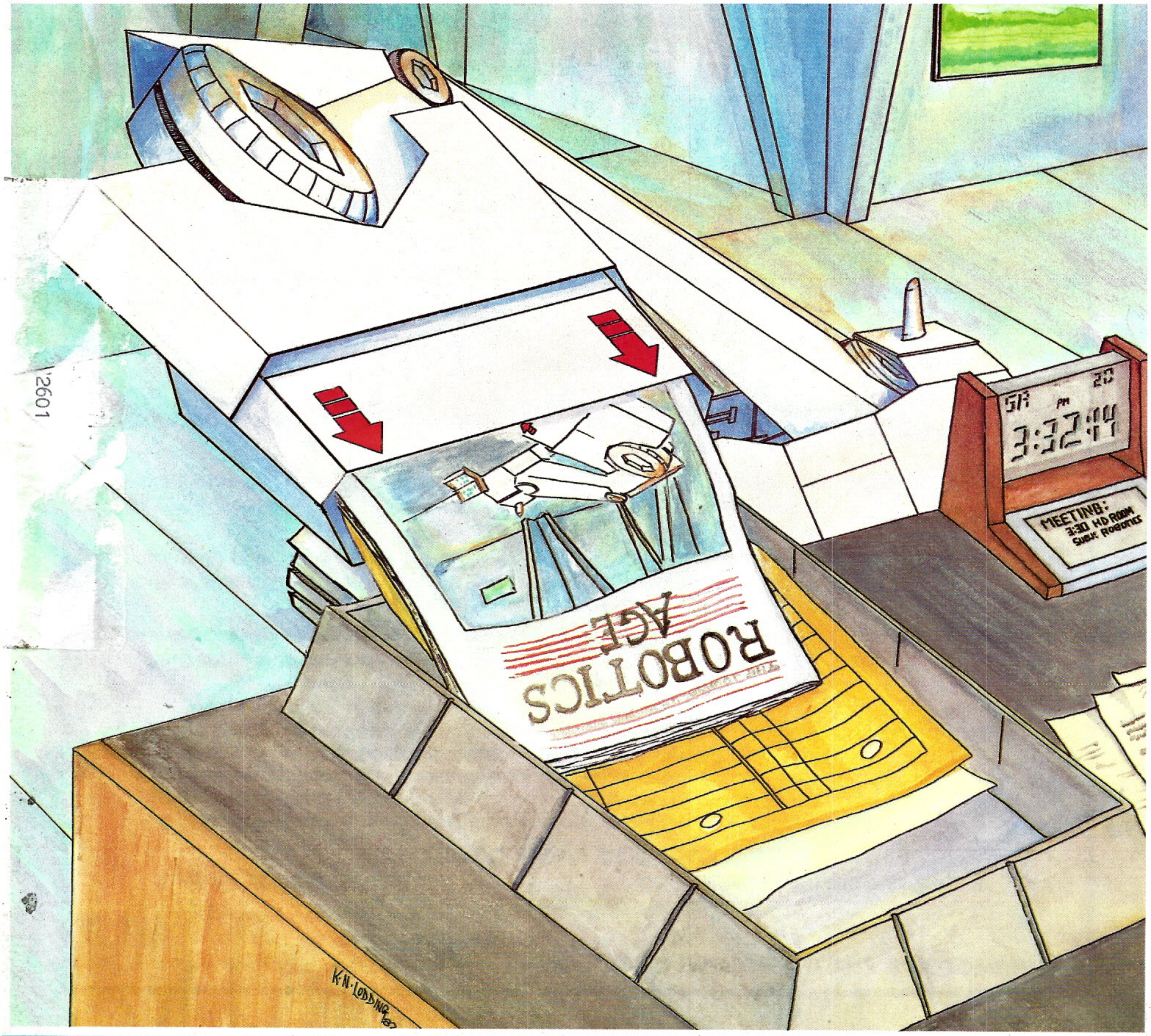
JAN/FEB 1983 VOL. 5 NO. 1 $3.00 USA/$3.50 CANADA

THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™



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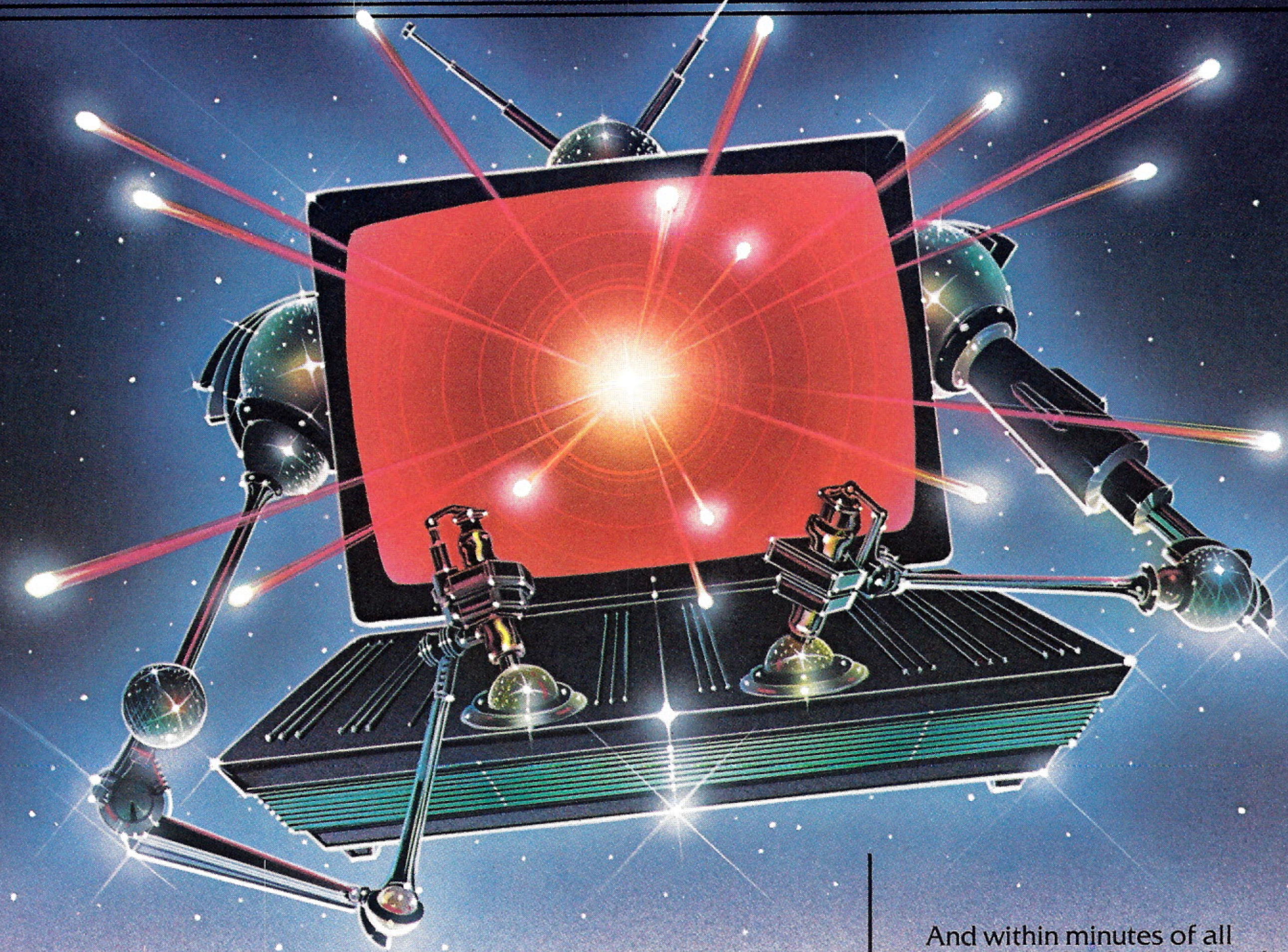

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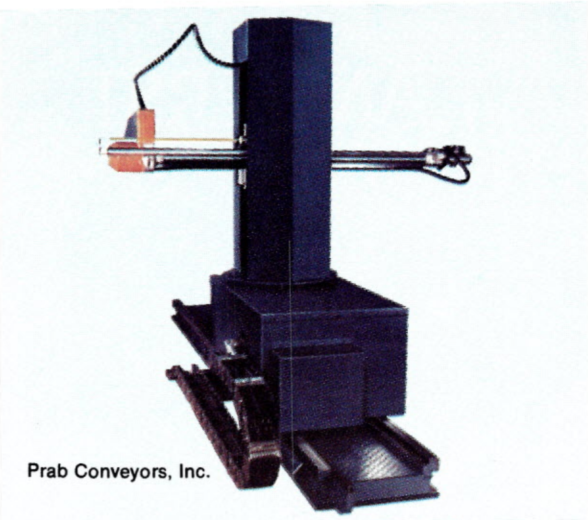
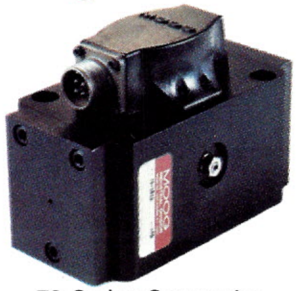
CIRCLE 2



Moog Servovalves



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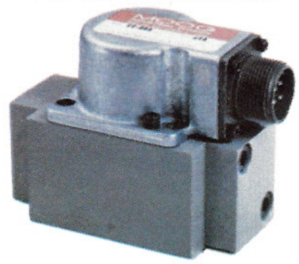

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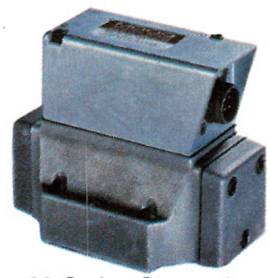

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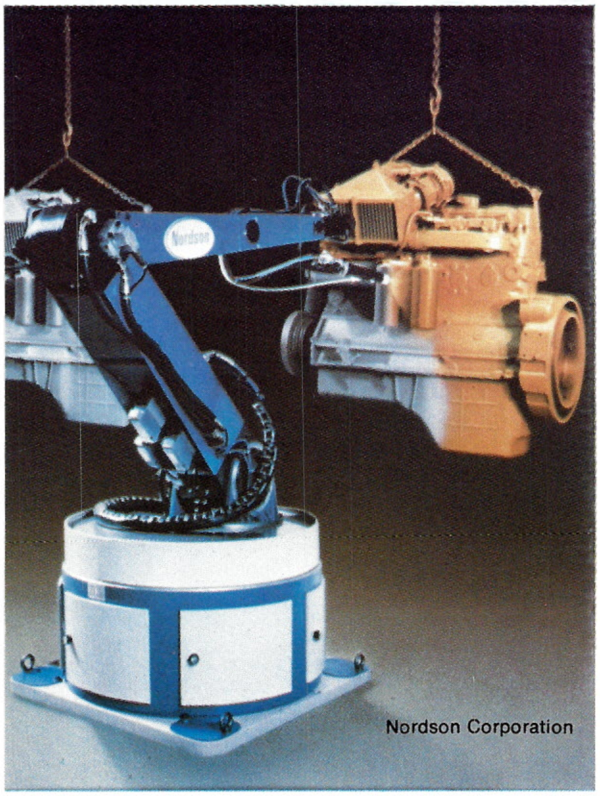

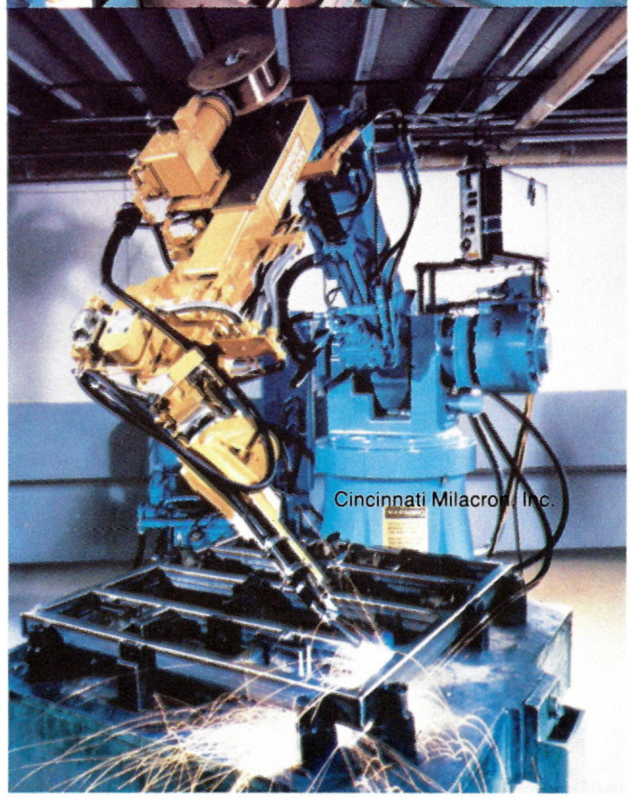

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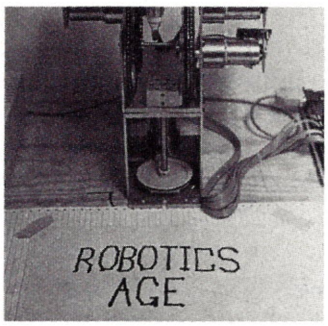
CIRCLE 14

THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

JAN/FEB 1983 VOL. 5 NO. 1



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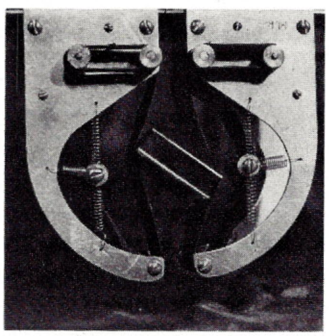

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EDITORIAL

FEATURES

DEPARTMENTS

About The Cover: The present state of the office mail delivery robot art is represented in Rodger Martin's article "Mailmobiles In The Office" beginning on page 20. Taking a cue from the idea of a mobile, autonomous, office, mail robot, artist Ken Lodding has created an ink and water color fantasy of the future. The extension Ken imagines in "Recursive Delivery" shows a fanciful office helper of the future placing a copy of Robotics Age on a desk. Some of the new mobile robot products we're beginning to see on the market might even be able to implement some of this function. Also — strange as it seems — Ken has provided us with yet another opportunity for a cover which is *not* a picture of an arm manipulator.

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Address all editorial correspondence to the Editor, at *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, N.H. 03458. Opinions expressed by the authors of articles are not necessarily those of *Robotics Age*. To aid in preparation of acceptable articles, the *Robotics Age* Authors' Guide is available upon request if accompanied by a self-addressed 8½ by 11 inch envelope with first class postage for 3 ounces. Unacceptable manuscripts will be returned if accompanied by a self-addressed envelope with sufficient first class postage. Not responsible for lost manuscripts or photos.

Editorial

What Can One Do With A Non-volatile Semiconductor Memory

BY CARL HELMERS

In the memory of every intelligent machine, there is a potential energy crisis if the machine employs conventional semiconductor memory technology. This is the crisis of power interruption. Unless continuously supplied with power, the conventional memory part will lose its patterns.

Various solutions to this fundamental volatility have been employed. There is the battery backup. New battery "keep alive" parts are standard components available on distributor shelves and as specialized designs. Batteries are fine, but even at microwatt-hours of consumption, a power interruption will occur when the battery capacity is exhausted. And the battery is yet another part that can fail. Similarly, for small computer systems, there are a number of new, uninterruptible power supplies. They come with typical power ratings in the several hundred watt range. But whatever the method of engineering, the battery is a bulky additional part, which is at best a kludge of a fix for the volatility problem.

The traditional method of achieving nonvolatility is via the read-only memory route. This is eminently successful. Products with large production runs such as consumer games and toys, tend to use mask-programmed read-only memories with fixed patterns. In smaller scale production and in the typical prototype laboratory, read-only memory practices of the past few years have very successfully used one of many ultraviolet-erasable read-only memory parts. There is still one fundamental problem — conventional read-only memory is not easily reprogrammed. In some cases, where fusible link technology is used, no reprogramming is possible. In others, where the ultraviolet erasable techniques are used, there is not much improvement. The part still has to be removed, given what amounts to a sun tan, then reprogrammed by a special fixture or through the use of special circuitry that complicates the design process.

Recently, there has been a fundamental improvement in the technology of semiconductor memory. There are several technologies involved, but the functional result is the same: it is now possible to design applications which use a memory part which is completely electronically programmable, yet nonvolatile with respect to removal of power. The names we've heard for this technology include EAROM (for electrically alterable read-only memory) and EEROM (for electrically erasable read-only memory) from several different sources. One source even called their part the "read mostly memory" to emphasize the fact that such a memory is hardly ever written to and is usually just referenced.

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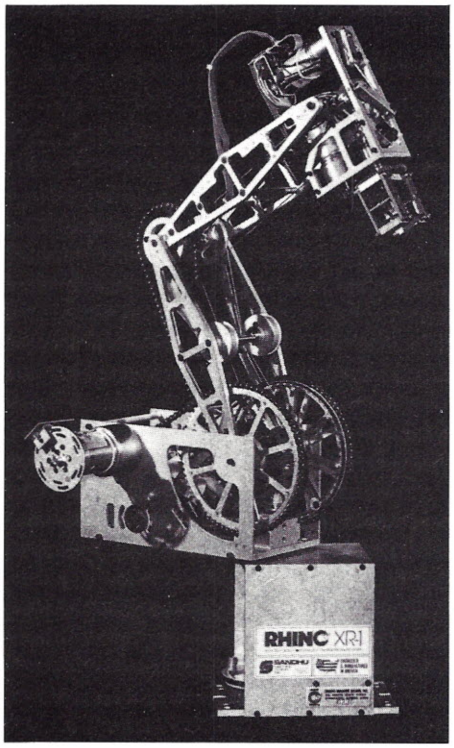

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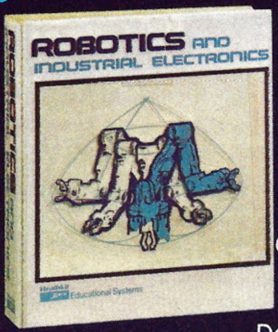
HERO 1 the most sophisticated microprocessor-controlled device since the microcomputer.

HERO 1 is a completely self-contained, electro-mechanical robot capable of interacting with its environment. Controlled by an on-board, programmable computer, it has electronic sensors to detect light, sound, motion and obstruction in its path.

Capable of seven axes of motion, the robot can be programmed to pick up small objects with its arm. It will also speak in complete sentences, using its voice synthesizer.



Remarkable though the robot is, its companion Robotics Education Course is an even more significant "first." It provides a thorough understanding of robot technologies, including robotics programming. Course features self-test unit reviews, experiments and final exam. Designed to be used with HERO 1, this 1200 page course is the most complete introduction to robotics available today.

HERO 1 is a computer on wheels. HERO 1 uses a 6808 microprocessor that controls 13 functions and sense boards. Its on-board processor can take it through complex maneuvers. The programming process is straightforward with provision for step-by-step debugging, enhancement and other corrections.

HERO 1 senses include: sound detection (frequency range 200-5000 Hz); light detection; ultrasonic ranging; ultrasonic motion detection; speech synthesis; and real time, four year calendar clock.

A completely mobile platform robot, HERO 1's motion abilities permit head rotation and arm rotation of 350,° shoulder rotation of 150,° arm extension of 5 inches, wrist pivot of 180° and wrist rotation of 350.° Gripper will open to a maximum of 3½ inches and rotate 90° at extreme extension. Payload capacity of arm is 8 oz. at maximum extension and 16 oz. at normal.

The remarkable HERO 1 robot is in production now, ready for you. Buy assembled or build it from a kit. Kit price is $1500 and the assembled robot is $2500, FOB Benton Harbor, or through your nearest Heathkit Electronic Center.

For full information on HERO 1 call 800-253-0570 toll-free. (In Alaska, Hawaii and Michigan, call 616-982-3411.) We'll give you the address of the nearest Heathkit Electronic Center and send you a booklet that gives details about the robot, the content of this course, and other information.

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Please send details on the HERO 1 robot and robotics course.

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RO-100A

CIRCLE 8

Editorial

The applications for the electrically erasable read-only memory function are bound up in its characteristics: it is now possible to dynamically maintain a history of a system without using either a one-shot writing technique (conventional ROM) or a complicated mechanical device (disk or tape storage). One or two parts allow one to simulate on a small scale what could be done with the mechanical backup storage. A key part of intelligent systems is adaptation and accumulation of a detailed history of the system. Using reliable semiconductor parts, it is now possible to engineer a new generation of such adaptive systems. Let's look at some of the obvious improvements over current technology that such parts can implement.

The Video Game Cartridge with History

An obvious starting point is one of the largest volume consumers of mask-programmed read-only memories: cartridges for video games and consumer software products. Obvious depends upon prior context. The way most video games and other cartridge software products work these days, is that there is one, and only one, program burned into a read-only memory at the time of manufacture. The programs are complex. The algorithms have numerous interaction subtleties. But they possess no history. All the good intelligent interactive games on large computer systems take advantage of the opportunity to record histories of play tagged to individual players. With such a strategy, there is no need to "get up to speed" in individual sessions. It is possible to design games which grow with the individual player.

The typical video game machine has a plug-in read-only memory cartridge which defines the software involved: an action game, an educational tutorial session, or other canned usage. The cartridges contain nothing but a read-only memory array for the game's microprocessor. The difference between read-only memory and one of the new electrically alterable read-only memories is relatively small: it represents merely a choice of parts used. With the exception of the line or two used for programming the memory, every other pin maps directly onto the same pinout as an older read-only memory part. Substitution of one or more of the EEROM parts for the equivalent ROM technology now gives us the ability to record usage history in the actual video game cartridge.

Thus, the cartridge itself can incorporate a number of unique and useful features related to the history of its use. For starters, it is now possible for the game designer to get more friendly. The cartridge can maintain a file of names of the individuals playing the game. For those cartridges without keyboards, this is not a practical possibility.

Many games have skill levels. These are often set currently at the beginning of play, based on arbitrary inputs from control keys. With an EEROM data base in the cartridge, skill levels can span many sessions rather than just the current session history since the last time power was turned on. Thus, if you play an action maze adventure game up to some level that brings out the Notorious Black Fuzzy Furd, you could have the option to resume at that level again after leaving the cartridge on a shelf for several weeks.

And of course, with the use of the EEROM approach, there are new possibilities for competitive contests. There is the idea of keeping a tally of recent game scores. These in turn could be shown off to friends and neighbors as proof positive that past achievements of ten billion points had occurred. Given the use of a keyboard and first name friendliness, the comparative aspect can be carried one step further. A list could be kept of players and highest scores.

The use of the EEROM as a recent scores data base is definitely appropriate at the cartridge level. One could conceive of use of the same technology in the game's central computer unit. Since the score tallies are really part of the game-oriented history, the natural association is with the cartridge.

Then, as suggested by my associate Ray Cote, there is the whole world of two-player, time-displaced games epitomized by Chess and Go. Here the cartridge game state data base really comes into its own. It is possible to use an appropriate game cartridge for an electronic version of correspondence chess. The current state of any particular chess game can be contained in a mere

Now, A New Hero

It's finally starting to happen. Heathkit has just (See page 40) announced a personal robot at a press conference in New York City.

According to the announcement, this exciting new development includes all the essentials of a mobile autonomous robot, including sensors, motion mechanics, arm, computer, and voice interfaces.

Editorial

64 bytes if we simply assign an 8-bit code to each possible chess piece on the 8 by 8 grid which is a chess board. This information, plus the recent history of the game, can be easily stored in just one of the new 2K byte EEROM parts. Network communications enthusiasts may scoff at the idea, but the slow passing of physical correspondence still persists in this world.

One technical problem has to be addressed. Some game units designed for read-only memory cartridges may have a fatal flaw with respect to this idea: if the memory write line is not available at the cartridge connector, then there may be no way to incorporate an EEROM in the cartridges for that game console. This varies with the foresight of the original game engineer's trade-off of short and long term goals.

But What of Robotics and EEROMs?

Let's just look at one idea here. As noted in a separate box, on December 1, 1982, Heathkit announced their first personal robotics product, the Hero-1. It is the prototype concept for a roving autonomous household robot. A mobile autonomous robot is hit doubly hard by the battery problem. It needs batteries for its data base, as well as batteries for its physical movement. Battery crashes of memory are a distinct and expected fact of life.

When you turn such a domestic automaton loose for the first time, it begins exploring. This pioneer algorithm builds up information about its environment. The baseline of the environment is changed as people move objects about in the environment. But the baseline stored in the semi-permanent memory remains. After the robot has been exploring its home environment for hours, days, or weeks, a data base will have been built up using self-programming adaptive features of well done software. To have a battery failure wipe out this learning would be catastrophic. One solution is the use of EEROMs in the adaptive learning memory used by appropriate applications software.

Fly in the Ointment?

There is, of course, one engineering disadvantage of the new technologies. The disadvantage is a limited write lifetime. The specifications for the new parts all give an upper limit on the number of times it is possible to write to the part. The write cycle lifetime is on a per-location basis within the addressable memory address space of the part. Whether specified byte-by-byte, or overall for the whole chip, the electrically

erasable read-only memory technology can only be designed into situations where writing is relatively infrequent — or where real-time checking of the results of writing is used to detect and compensate for write failures by allocating bytes from a reserve.

Overall, A Respectable Increase in Intelligence. . .

The overall conclusion is that the use of low-cost electrically erasable read-only memory is an important trend in a number of traditional and untraditional designs. The advantages of long-term adaptability will enable kinds of products which would not be possible otherwise. Without the EEROM, the truly intelligent adaptive video game would not be possible. With this technology, the idea of the adaptive mobile robot system becomes more feasible through reductions in power budget reserves and elimination of non-electronic storage requirements.

On Contests

As advertised in our last issue, SEEQ, Inc. just ran a design contest for use of the EEROM technology, with a January 10, 1982 deadline, slightly after the mailing of this issue. I've been asked to participate on the panel of judges for the SEEQ Application Design Contest. This editorial was written as a "what if" backdrop to later evaluation of entries. Design contests are an excellent way to call attention to new technologies and their uses. I'll look forward to more of these as time progresses.

About A New Survey — And A New Reader Response System

Every enterprise has miscellaneous details. *Robotics Age* is no different. In this issue, are two such details which involve interaction with readers: the Second Annual *Robotics Age* Reader Survey, and the implementation of our new *Robotics Age* Reader Response System (RARRS for those who love acronyms).

The *Robotics Age* Reader Survey is an important part of the growth and evolution of the intelligent machines field. It is our way of documenting for historical purposes the demographic information about a particular set of clever and innovative, intelligent machine design oriented individuals — the

readers of *Robotics Age*. Your participation in this survey is entirely voluntary. We pay the postage on the self-mailing business reply form bound into this issue. The information determined will, of course, be made public in the form of a commentary we will publish after results have been analyzed. The cutoff date for receipts of forms for the 1983 *Robotics Age* Reader Survey is March 15, 1983.

Also beginning with this issue, you'll find a new format of Reader Response Card, reflecting a new, improved system. Implemented by yours truly as a set of Pascal programs running on a UCSD P system, our new *Robotics Age* Reader Response System will greatly improve handling of your requests for further information from advertisers and companies featured in new product stories.

It is easy for you to participate in the process of getting further information, brochures, etc. Simply fill out the card bound into every issue of *Robotics Age*. Circle the reader response numbers for the companies or organizations of interest to you. Answer the questions on the card, apply appropriate postage, and mail the card to us.

When we receive your card, your name and address as shown on the card is entered along with a list of the numbers you circled. A reader response data entry program accomplishes this task in an interactive fashion using an ordinary terminal. Then, whenever a significant batch of cards has been accumulated, a reader response print program is used to print a list of all the names and addresses of individuals who circled each number. This list is then sent to the company or organization corresponding to the reader response number.

AUTHOR GUIDE NOW AVAILABLE

We have now completed the first *Robotics Age* author guide. This 26-page document contains detailed information about technical writing in general and writing for *Robotics Age* in particular. Potential authors can obtain a copy by sending a self-addressed, 9×12 envelope, plus $1.00 to cover postage.

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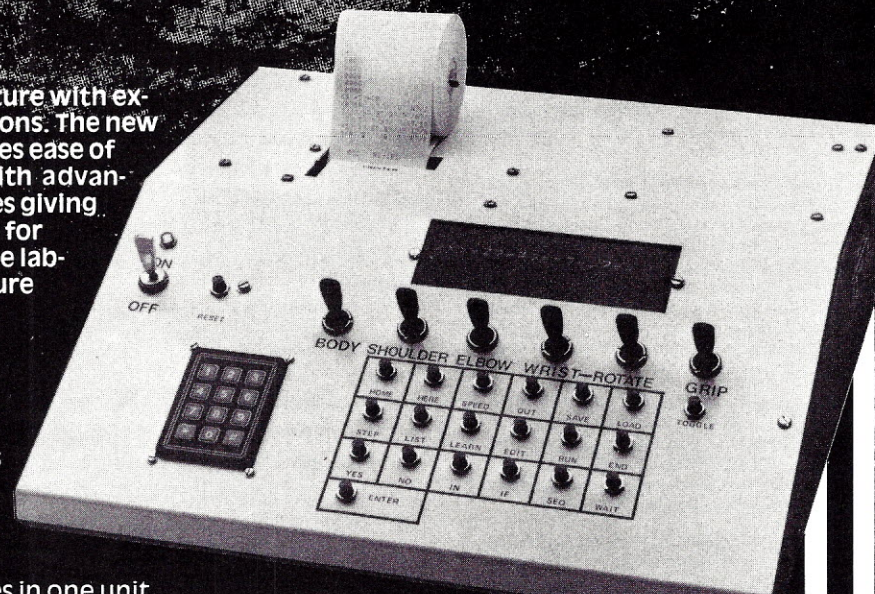
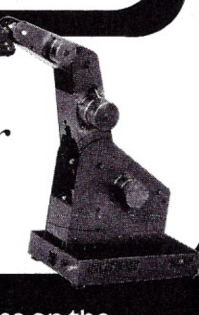
Robotex is reaching into the future with exciting microelectronic innovations. The new RC-101 robot controller combines ease of programming and operation with advanced decision-making capabilities giving it virtually unlimited versatility for display use, the classroom or the laboratory. Join Robotex and venture into the world of Robotics . . . a glimpse of tomorrow!



- **PROGRAMMING EASE:** The RC-101 simplifies robot programming and operation by combining manual "Teach-in" programming, decision making capability and numerous interfaces in one unit.
- **REAL WORLD INPUTS/OUTPUTS:** Standard features of the RC-101 include six TTL level or micro-switch inputs, four photocell inputs with adjustable sensitivity and two contact closure outputs.
- **RTROL: ROBOT CONTROL LANGUAGE** A language (compatible with "Teach-in" programming) which allows program decisions based on any of the input conditions. **RTROL** programs can be easily created, displayed and edited with a built-in keyboard, alphanumeric display and printer.
- **DURABILITY:** The RC-101 is constructed to withstand practical industrial use.
- **FLEXIBILITY TO CONTROL DIFFERENT ROBOTS:** The RC-101 is currently offered with software for driving Mitsubishi's RM-101 "Movemaster" micro-robot and Sandhu Machine Designs' XR-1 "Rhino." Software for other robots is forthcoming.
- **CASSETTE PROGRAM STORAGE:** This built-in feature allows control programs to be saved or loaded with a cassette storage interface.
- **SOFTWARE:** An **RTROL** language subset for the RM-101 or XR-1 is available for use on the Apple II + or Franklin Ace.

RHINO XR-1

SANDHU MACHINE DESIGN INC.



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CIRCLE 19

Media Sensors

Scientific American *September 1982*

The September 1982 issue of *Scientific American* devotes seven major articles to the mechanization of work. Coverage ranges from the purely technical aspects of automation to the moral and social aspects of increased automation. The following extracts provide a taste of the entire issue.

In "The Distribution of Work and Income," economist Wassily Leontief states, "Although current business publications, trade papers and the popular press abound with articles about 'automation' and 'robotics' and speculation on the economic impact of these developments, only the governmental and scientific agencies of Austria have produced a systematic assessment of the prospective consequences of the present revolution in laborsaving technology in a modern industrial economy."

In another article, "The Mechanization of Design and Manufacturing," Thomas Gunn states, "Data processing technology can be applied to the control of three general kinds of machines in the factory: machines that store, retrieve, or transport materials, machines that process the materials, and robots." Mr. Gunn also discusses the use of automation on factory floors. He says, "Dozens of robots might be linked by a hierarchy of computers, much as direct-numerically controlled machine tools are today."

In "The Mechanization of Commerce," Martin L. Ernst says that "another major application is the mechanization of handling operations. The possibilities include aids to essentially manual operations by means of fork lifts and similar equipment that incorporate sensors and microprocessors; operator-controlled but nonetheless semiautomatic order-picking systems, and completely mechanized order-picking systems that can include automatic palletizers and depalletizers, devices that move cartons onto and off of portable platforms."

Wayne D. Rasmussen, in the article, "The Mechanization of Agriculture," expresses the opinion that, "with one exception, no major further advances in the mechanization of agriculture are now in sight. . . ." According to Rasmussen, "the one exception is the application of computers to farm management. . . . This application should lead to more efficient management of machines and energy and should help in other farm operations such as cost accounting, mixing feed and deploying fertilizers and other resources efficiently."

Robert Marovelli and John Karhnak, authors of "The Mechanization of Mining," find "changes in the technology of mining through the remainder of the century will be evolutionary rather than revolutionary. A period of at least 10 to 20 years is needed for a new mining technology to replace an older one. The reasons are the same as those that could be cited in any other industry: the high capital cost of new equipment, the inclination of operators to stick with proven methods and uncertainty about the performance of new devices. A special obstacle to innovation in underground coal mining is that a change in a subsystem, such as haulage, may require a change in the entire mining system. Nevertheless, longwall mining, which requires the most radical change of all, is expected to grow, depending in part on how successfully it can be adapted to thin seams in the East and thick ones in the West."

Vincent Giuliano, in "The Mechanization of Office Work," says that "whether a company's business is in farming, mining, manufacturing, transportation, or retailing, its management marketing, distribution, and other controls are basically office-centered, information-handling activities. . . ." He concludes that "the mechanization of office work is an essential element of the transformation of American society to one in which information work is the chief economic activity."

The September issue of *Scientific American* puts a variety of automation topics in clear perspective. After the almost encyclopaedic coverage of the seven major articles, the reader is left with Leontief's timely reminder that we do not currently have any "systematic assessment of the prospective conse-

Continued on page 22

Address Requests

Dear Editor,

Can you please send me the address of the International Institute for Robotics?

Sincerely,
Heironamous Hedgerly

Over the last several months, we have received several similar requests. Listed below are the addresses of the most often requested organizations.

American Association for Artificial Intelligence (AAAI), *445 Burgess Drive, Menlo Park, California 94025. Phone: (415) 328-3123.*

American Federation of Information Processing Societies (AFIPS), *11815 North Lynn Street, Suite 800, Arlington, Virginia 22209. Phone: (703) 558-3600.*

Association for Computing Machinery (ACM), *11 West 42nd Street, Third Floor, New York, New York 10036. Phone: (212) 869-7440.*

International Institute for Robotics, *Box 210708, Dallas, Texas 75211.*

Robot Institute of America, *PO Box 930, Dearborn, Michigan 48128. Phone: (313) 271-0778.*

Robotics International (RI/SME), *PO Box 930, One SME Drive, Dearborn, Michigan 48128. Phone: (313) 271-1500.*

Machine Shop Interest

Dear Mr. Helmers,

I have been an avid reader of *Robotics Age* for some time and thoroughly enjoy the magazine. I am very glad to see the number of small advertisements for bits and pieces growing with each issue. They are a very real resource for the robotics constructor.

In the January/February 82 "Notes" (page 15), you wrote of ". . . a continued emphasis on the technology and techniques for experimentation and implementation of robotic systems. The tools and products we talk about will range from inexpensive, personally owned computers, robot arms, and machine shop equipment, to the sophisticated computer aided design, and artificial intelligence equipment now coming to the market." The machine shop equipment aspect is what I wish to see developed.

Robot arms, pick and place manipulators, etc., are described as free-standing units, but rarely as adjuncts to machine tools. While most shop operations are turning, boring, milling, or grinding on specialized machines built for these purposes, these are ideas and machines around which all machining operations can be combined. The so-called universal machine tool has never found widespread favor in industry since there is a lot of time spent in changing from function to function. Manufacturing has tended toward individual purpose machines, each with an operator skilled in its functions. With the advent of sophisticated software, visual control systems, and manipulators with several degrees of freedom, I think it is time the universal type of machine is examined again. With this, the tool changes and shifts of machine components are under direct control of the microprocessor, and the placement of workpieces into clamps or vises on the machine table can be done by the manipulator on the machine. The dimensioning of the workpiece is specified by the *software*, and not necessarily by the construction of elaborate mechanical jigs or fixtures, as is presently done.

This leads to the idea of a single universal machine tool which can replace a variety of specialized machines. I suggest you ask one of the talented contributors to *Robotics Age* to investigate this. It would be of great value to the small shop operator who is facing rising labor, tooling, and material prices.

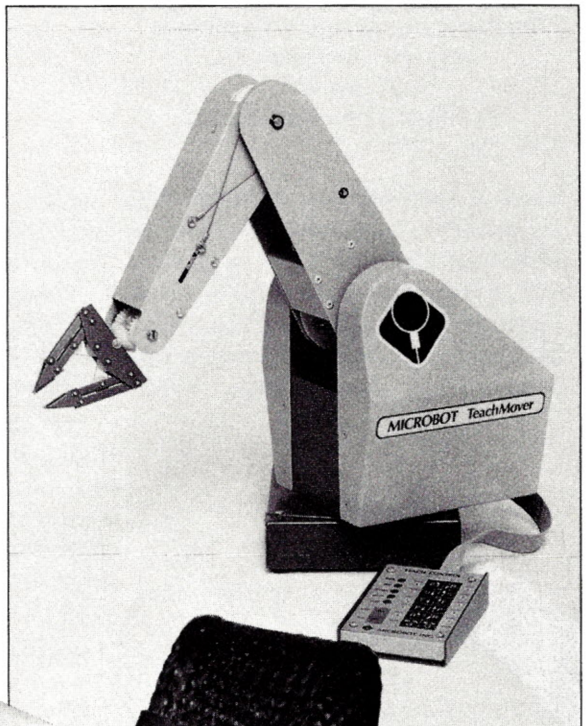
In terms of specific leads I offer two sources, one available now, off-the-shelf, and one suitable for the amateur or very small shop at the prototype level.

The Labormil manufactured by Anthony H. Croucher Ltd. is a basic universal type of machine tool which could be readily fitted with x-y-z encoders and an off-the-shelf robot arm. This machine is capable of all the machining functions with an absolute minimum of tooling/workholder changes. This makes it suited for robotic assist. The Labormil with all the accessories, import fees and shipping costs around $15,000 (my guess based on an earlier price list). If this was coupled with the IBM 7535, AML, and the Personal Computer ($28,000 + $4575, (*Robotics Age*, July/August 1982, page 29) to cost a total of around $48,000, it is still competitive with advanced machine tools with less flexibility. The 7535 system can also be used as an assembly device, using the Labormil carriage/milling table as a work surface.

Turning to the small-scale or home shop level, a universal type of machine tool was built by Mr. David Urwick in the 1950s for his own use. This was recently featured in the British advanced amateur machine journal, *Model Engineer*, 2 July 1982, pages 12-16. His x-y-z concept utilizes a unique triangular keyway on the vertical column. I have urged Mr. Urwick and the editor of *Model Engineer* to produce a series on this machine and to make the castings or finished machine parts as a kit, available to amateurs. Referring to "A Homebuilt Computer Controlled Lathe," by Jan Towland, *Robotics Age*, May/June 1981, pages 28-34, he constructed his own lathe and controlled it with a Commodore PET computer and low-cost stepping motors. This allows him to do profile turning at low cost, which he doesn't mention, but I would estimate as less than $6000 for the unit. Thus, the hardware has the potential for being operated at the amateur or small machine shop level if matched with a small robot arm of the Microbot or Rhino type.

Best regards,
J.W. Stryker
USAID-C
Box 333
Maseru 100
Kingdom of Lesotho
Africa

Join the robotics revolution now!



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RA

CIRCLE 12

THE MOVE-MASTER RM-101

Mr. Venkitaswamy Raju
Rochester Institute of Technology
Mechanical Engineering Technology
One Lomb Memorial Drive
P.O. Box 9887
Rochester, New York 14623

The robotics revolution is here to stay. Industrial organizations and educational institutions have given due recognition to this fact. This recognition has resulted in a large number of engineering schools offering programs in robotics. Many of these schools, however, face financial constraints and are unable to equip their laboratories with large "industrial" robots. This, in turn, has created a market for low-cost "educational" robots. Companies large and small have developed products to meet the demands of this market. Microbot, Feedback, Sandhu Machine Design, Colne Robotics, Amptronics, and Mitsubishi of Japan are just a few. The cost of educational robots ranges anywhere from several hundred to several thousand dollars.

This article describes the features of one such educational robot, the Move Master RM-101, designed and manufactured by Mitsubishi Electric Company of Japan. Mitsubishi responded to the demands of the educational institutions in Japan and came up with the Move Master RM-101 in early 1982. It is now available in the United States.

The RM-101 is a sophisticated microrobot that performs complex manipulations in response to simple commands. Although it is not an industrial robot, it uses the same principles of operation.

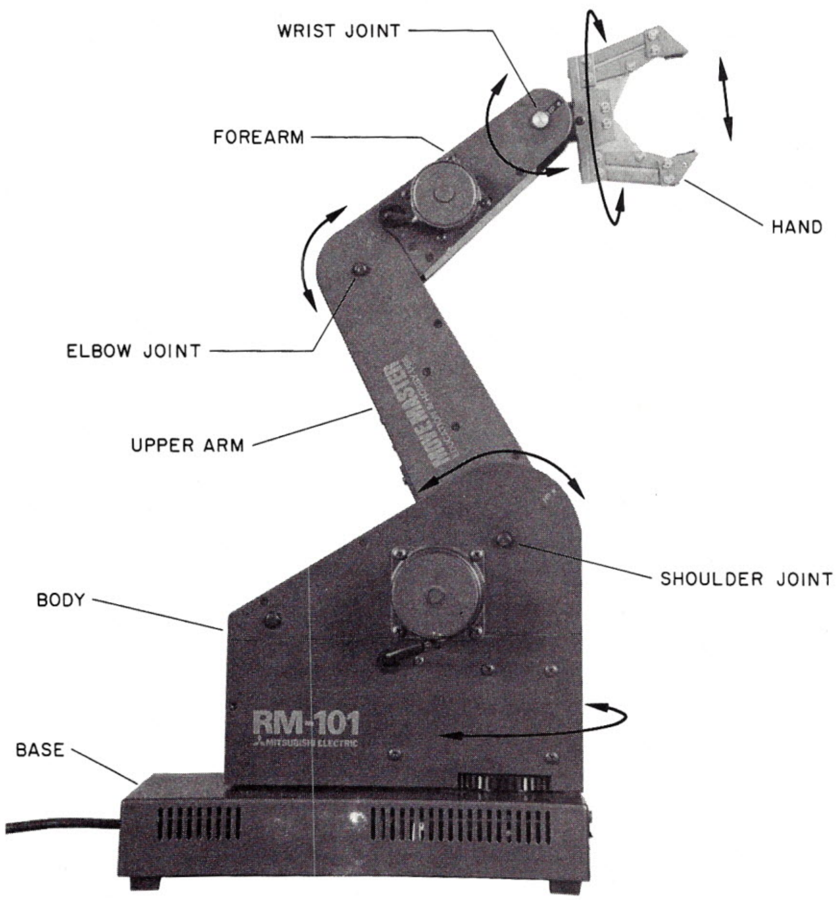


Photo 1: The Move Master RM-101 stands 10.4 inches high and consists of a base, body, upper arm, forearm, and hand. The motion is controlled by six motors: one each for the body, shoulder and elbow; one for driving the hand; and one each for driving the left and right wrists. The RM-101 can be controlled from a microcomputer by 11 basic commands.

Mechanical Description. The RM-101 stands 264 millimeters (10.4 inches) high and weighs 10 kilograms (22 pounds). It offers completely independent rotation around six axes—five degrees of freedom. The payload capacity of the robot at full extension is 500 grams (1 pound, 2 ounces). The RM-101 has six major mechanical components: the base, the body, the upper arm, the forearm, the hand, and the fingers (grippers). These components are shown in photo 1. Each component is connected to its neighbor by a pivoting or rotating joint. The base of

Acknowledgements: I would like to thank Dr. Dennis Nystrom, Professors Dave Baker and Louis Gennaro and Mr. Stephen Walker of RIT, and Mr. Henry Kambe of Mitsubishi for their help.

the robot remains stationary on a horizontal surface and provides support for the rest of the robot's components. The base contains a microprocessor, a driver board, and control switches.

The RM-101 employs simple and reliable pulse motor drives which allow precise electronic logic control by standard microcomputers. There are six stepping motors (see figure 1): one for the body (waist), the shoulder, and the elbow; one for driving the hand; and one each for driving the left and right wrists. The motor that drives the body (called M_1) is enclosed in the body itself. The motors that drive the hand (M_6) and the shoulder (M_2) are attached to the right and left sides of the body. The wrist control motors (M_4 and M_5) are fixed to the sides of the forearm. The motor that drives the elbow (M_3) is fastened to the right side of the upper arm. The right and left directions specified here are as seen from the front of the robot.

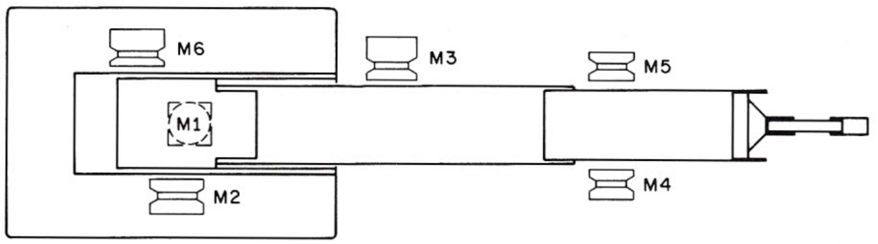


Figure 1: The Move Master RM-101 uses six stepping motors: M1 (body), M2 (shoulder), M3 (elbow), M4 and M5 (wrist control), and M6 (hand).

The body of the robot rests on the base and rotates about a vertical axis which passes through the base. The body rotation is limited to 240 degrees about the vertical axis.

The upper arm is connected to the body at the shoulder by a horizontal pivot. The upper arm at the shoulder rotates about an axis parallel to the base, and its angle of rotation is limited to 150 degrees (75 degrees forward and 75 degrees backward).

The forearm is fastened to the upper arm at the elbow with a horizontal pivot and is rotated about that point. The rotation at the elbow is limited to 120 degrees (75 degrees forward and 45 degrees backward).

The hand is connected to the forearm at the wrist with a combination horizontal pivot and miter assembly. The motors that control the hand movement at the wrist can be operated either to bend the hand up or down about the pivot or to rotate it about its own axis. The upward and downward movement of the hand at the wrist is limited to 180 degrees; wrist rotation can move through 360 degrees. The fingers attached to the hand open to a maximum spread of 80 millimeters (3.15 inches). The overall length of the robot from the tip of the fingers to the far end of the base is 690 millimeters (27.16 inches).

Computer Interface and Software. The base of the RM-101 houses a Z80 microprocessor with 16K of read-only memory (ROM) and 8K of static, programmable memory. The ROM contains a self-diagnosis program that puts the unit through its paces. A standard Centronics interface allows the robot to be connected to a wide variety of computers. Both the read-only and programmable memories can be expanded.

The programming languages used in the operation of RM-101 include BASIC, assembler, and M-ROLY, a programming language tailored to the specific needs of the robots. M-ROLY, with its special command set, flexibility, and ease of use, takes its name from "Robot-Oriented Language by Yahagi." Yahagi is the consultant who cooperated with Mitsubishi Electric in the development of the language. M-ROLY is a symbolic language for robots which is similar to the VAL language used by PUMA robots manufactured by Unimation. M-ROLY software is available for five different personal computers.

The personal computers recommended for use with the RM-101 are: Apple II, Mitsubishi Electric's MX-6000, Mitsubishi Electric's MULTI-16, Nihon Electric's PC-8001, and Sharp's MZ80B. A special cable is provided to connect the robot with these personal computers. For connection to a computer other than those listed, the manufacturer recommends a connector-free cable sold separately by Mitsubishi. The RM-101 is also supported with special applications software packages and software for controlling the robot with a light pen, digitizer, or joystick.

Although the RM-101 can be controlled by many different models of microcomputers, Mitsubishi Electric has developed a system specifically for this purpose, the MX-6000 microcomputer. With its CP/M operating system, the MX-6000 has the ability to control two RM-101s for two-handed operation. The system has a built-in video display, 64K of programmable

memory, a printer, and a floppy-disk drive. The MX-6000 supports several high-level languages.

Operating Principles and Features. In general, computer-controlled devices operate as follows:

1) The operator enters his intentions with a logical program that the computer can read.
2) The computer decodes the program, performs necessary calculations, and produces output signals acceptable by the device at appropriate times.
3) The computer monitors the operation of the device and waits for the next timing signal. In this way, every movement of the device is controlled.

With the RM-101 software and powerful commands, sophisticated operations can be performed easily. The features of the RM-101 system software are as follows:

- Simple commands are used for computer input.
- A computer is built into the robot. The computer is preprogrammed to receive the signals corresponding to the above commands and to decode them in order to control the operations internally.
- In this decoding process, the limiting conditions of the robot itself are taken into consideration. Since the microcomputer can perform a different operation during this time, sophisticated systems, such as controlling two robots or using a vision system, can be realized.

Command Descriptions. There are 11 basic commands for directly controlling the RM-101. Four additional commands are used when an RM-101 is used with a vision system, or when it is used as part of a multiple robot system. The four additional commands will not be discussed here.

The commands for directly controlling the robot are as follows:

HOME: Moves the robot to the home position. At the home position, the upper arm is at a 45 degree angle to the base; the forearm and the hand are parallel to the base. Home position can be established manually through an operation called Test Mode 1. There are two test modes, and they are used in the beginning of the operation for testing the robot's functions. During the test modes, the robot carries no loads.

POSITION: Specifies a location. A location in space is identified with a location number and the number of motor steps to this location from the home position. A sample command format is: (P1, +2000, 0, 0, 0, 0, 0). A simple translation of this is as follows: a location with a position number, P1, has been identified for the robot. This location is reached from the home position by the operation of the motor M_1 (the motor that controls the body movement) for 2000 steps in the clockwise direction. In reaching this location, the other five motors moved zero steps. Each step in the stepping motor M_1 corresponds to 0.04 degrees angle of movement. In this case, the body of the robot rotates 80 degrees (2000 times 0.04

degrees) from its home position. Up to 100 such positions can be stored with the standard programmable memory supplied.

MOVE 1: Rotates each of the robot joints by the number of steps specified. A sample command format is: (I +2000, −500, 0, 0, 0, 0). This means that the motor M_1 is rotated 2000 steps to move the body 80 degrees in the clockwise direction from its original position, and the motor M_2 is rotated 500 steps to bring the upper arm downward from its original position. When the user is not interested in identifying this location with a POSITION command, an I is used instead of P1 in the input format. When the MOVE 1 command is executed, each joint is driven so that the tip of the hand moves in a direct line. All the joints move and stop simultaneously.

HERE: Stores the robot's current position.

Assume that the robot has already been moved to three positions with position identification numbers P1, P2, and P3. A MOVE 1 command has been used to move the arm to a fourth position. The input format of the fourth position as given in the MOVE 1 command is: (I + 2000, −500, 0, 0, 0, 0). This does not have a position identification number. If the operator decides to store this position, the command HERE should be used with the input format E4. This results in (+2000, −500, 0, 0, 0, 0) being stored as position 4 with respect to the home position. Up to 100 such positions can be stored.

MOVE: Moves the robot to the position specified by the location number in the E format (HERE) or the P format (POSITION). The input format is M(a), where (a) is the location number.

NEST: Moves the robot to the home position.

G.CLOSE: Closes hand grippers. When this command is executed, the grippers are closed to their limit. The system automatically determines the force needed to close the grippers.

G.OPEN: Opens the grippers in the robot hand. G.OPEN opens the grippers to their limit.

SPEED: Determines how fast the robot moves during a MOVE 1 command. One of the five possible speeds, S1, S2, S3, S4, or S5, must be specified before a MOVE 1 or MOVE command is executed.

TIME: Temporarily halts the robot arm. A sample command format is T6. This means the movement of the robot is delayed for six seconds.

LIMIT: Controls the range of movement of each joint. The joint movements are monitored based on the home position. If the number of steps entered in the program exceeds the movement range of each joint, the system stops the movement, and the error light is turned on.

The RM-101 operating commands and an example of the command format are presented in table 1.

The RM-101 is a low-cost robot with the features of an industrial robot. It is rugged in construction, quick to obey, and easy to program for intricate sequences of complex movements. Its applications are limited only by the user's imagination. □

MOVE MASTER RM-101

Applications	Educational, hobby
Construction	Jointed, metal plate
Degrees of freedom	Five
Operational angular coverage	
Body rotation	240 degrees
Shoulder rotation	150 degrees (75 forward, 75 back)
Elbow rotation	120 degrees (75 forward, 45 back)
Wrist bending	180 degrees
Wrist rotation	360 degrees
Grasp of hand	80mm (3¹/₈ in.) (maximum)
Lifting capacity	500g (1 lb. 2 oz.) excluding weight of hand
Maximum operating speed	7cm/s (2¾ips) at tip of hand
Positioning precision	0.3mm
Control section	
Drive motors	Six stepping motors
Speed control	Trapezoidal waveform control
Axial control	Simultaneous control of all 6 axes
Interfaces	Centronics-type, with special-purpose cable for connection to microcomputers
Programming languages	BASIC, assembler and M-ROLY
Power supply	115VAC, 50/60Hz, 60W
Power cable	2m (approx. 6 ft. 6 in.), supplied
Weight	Approximately 10kg (17 lb. 5 oz.)
Accessories (standard)	Two hand attachments, instruction manual, wire-connection ring, finger pads, etc.
U.S. Distributor	E & L Instruments, 61 First St., Derby, CT 06418

Command	Example of the Command Format
HOME	(H)
POSITION	(P1, +2000, 0, 0, 0, 0, 0)
MOVE	M1
MOVE 1	(I +2000, −500, 0, 0, 0, 0)
HERE	(E5)
NEST	(N)
G. CLOSE	(C)
G. OPEN	(F)
SPEED	(S3)
TIME	(T1)
LIMIT	(L1)

Table 1: Summary of M-ROLY commands and command formats.

MAILMOBILES IN THE OFFICE

Rodger C. Martin
Goosebrook
RR2 Box 722
Peterborough, New Hampshire 03458

However grudgingly, the American work force has accepted the computer as a work mate to be dealt with on equal terms. But the computerized tool, until recently, has remained motionless, locked in its own space.

How does that work force react when the computer grows legs, arms, and eyes and travels from office to office and from building to building? The computerized robot, much like the Model T compared to its potential, has begun its journey. Insurance companies in particular have found automated robots useful for delivering interoffice correspondence.

The following is a light-hearted look at how companies and employees react to robots in the office environment.

Office Robots.

The robots are coming! The robots are coming! Not R2-D2 but Eight-Ball, Little Go-Beep, Archie Bumper, and a host of relatives. They make deliveries every few hours at a rapidly growing number of surprised and satisfied New England Businesses. Who are these automated employees of the office staff? They are the self-propelled, driverless, not-run-by-human hands mailmobiles, products of a Michigan Company. And if you think secretaries won't attach themselves to robots doing hourly delivery runs for them, you've got a "Beep-Beep" surprise coming. Little Go-Beep (Peerless Insurance) has just celebrated her fifth birthday in Keene, New Hampshire, and she seems happy to be there. They are happy to have her.

The mailmobile is a 700-pound traveling mail carrier, a constant receiver and dispatcher of interoffice paperwork. It looks like a thin van and is capable of transporting hundreds of pounds of mail or supplies throughout a building on a continuous basis.

Oscar (Aetna Insurance) has four "eyes" underneath his carriage. One eye sees an inert phosphorus trail invisible to humans. Two other eyes see to the left and right, keeping Oscar on track. The fourth eye finds his stopping points or mail stations. When Oscar reaches a station, he beeps his arrival and waits up to half a minute for someone to take what he has or give him what he is to carry. At the end of his short stop, Oscar goes on to the next station. Oscar can be programmed to wait for a shorter time. Peerless Insurance has Oscar stop for only 10 seconds at any point. To stop him for longer stays, push the red stop line that rings the perimeter of the robot.

Blue Eyes (Massachusetts Mutual Insurance) is another reliable worker. She has suffered from a condition brought on by the sun. At certain times each year, the sun shines through windows at the Massachusetts Mutual building at such an angle that Blue Eyes is blinded temporarily. Twice a year, she stopped work until the sun moved to an angle that no longer blinded her. A Massachusetts Mutual employee figured out that there was nothing wrong with Blue Eyes that a pair of sunglasses could not solve. They gave her a pair that looked like blinders which covered the bottom of her carriage and shielded her electric eyes from the glare.

Service is a problem in New England, as Hartford, Connecticut is the major service point. House calls from Hartford to northern New England tend to be costly and not immediate.

What happens if 700-pound Archie Bumper decides to run you down? The tracks he follows are invisible, and the robot, other than its beeping, is noiseless. It is not likely, however, any mailmobile will overtake you. Archie's top speed is one mile per hour; that gives most primates a considerable speed advantage. I impersonated an office staffer bent over cleaning up the leftovers from last night's office party. Archie stopped eight inches from me and waited for me to finish. If the person in Archie's way fails to move, Archie waits a few seconds, then sneaks up a few inches to "see" with his electric eyes if the person is still there. If his path is still blocked, Archie gently nudges the obstacle and waits for help. It takes 8 ounces of pressure against any bumper to stop him.

Patty Wagon (Continental Can) runs on regular 110-volt AC. She likes to be plugged in all night but will run fine for a week if you give her weekends to store up. Since Patty Wagon generally does not work during off-peak electrical hours, she can be charged during this less expensive time.

Tobor (robot spelled backward) costs $14,000 without options. In a large business, this may be less than the annual cost of the time a business pays pages, secretaries, and others who deliver mail. Gordon Adams at Peerless believes that Little Go-Beep paid for itself within two years. She does the work of one-and-a-half people.

Cary R. Pidgeon does have limitations. He is left-handed, needing only

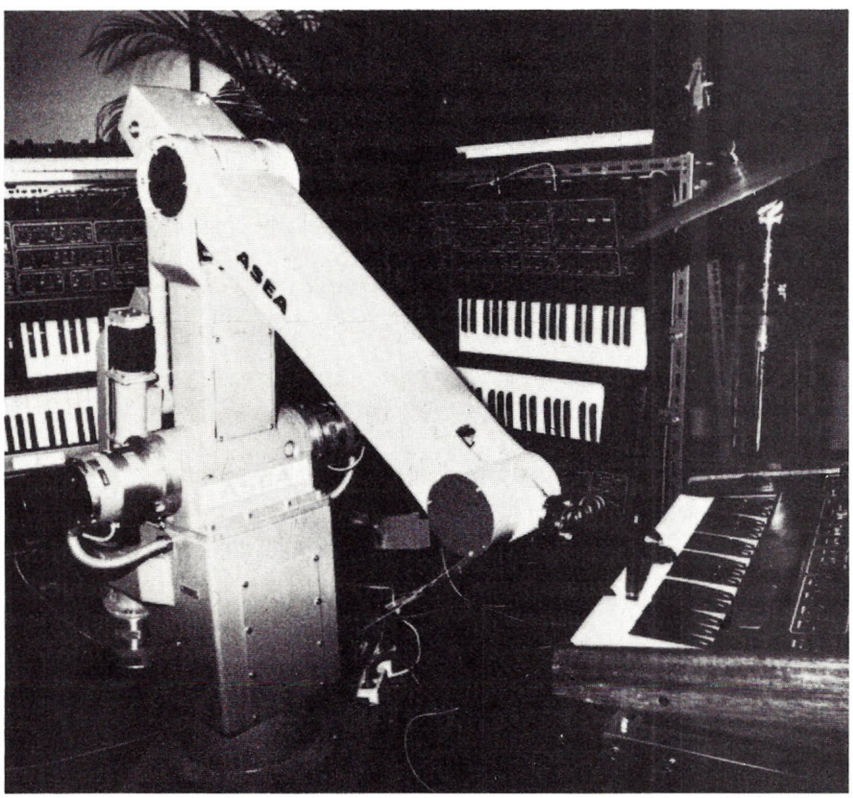
a 6-foot turning radius in that direction, slightly more to his right. Keith Holmes, Lear Siegler's New England sales representative was asked if Car 51 (51st. floor) could go up or down stairs. His reply, "Yes, once — down!" The mailmobiles are fair game for the company practical joker. At one company, Erich (electric robot internal communications handler) and Amailia followed each other on the same route. Each went about his and her business until someone turned Erich around and had him meet Amailia face-to-face in front of a company vice-president. The confrontation consisted of an 8-inch staring match, flashing lights, beeps, and ended with an 8-ounce kiss.

Gwen Greeley, public relations person at Peerless, said Little Go-Beep caused quite a stir her first week on the job, but since then it has been business as usual. The only ones who notice now are new employees and visitors. Peerless employees dress Little Go-Beep for holidays: Santa hats at Christmas, eggs and ears at Easter, masks at Halloween. She also serves as present deliverer on birthdays.

Regardless of the machine, if it has characteristics people can identify as human, they will personify the machine, as shown by some of the other names the mailmobile has acquired: Furn. I, Ture, Bionic Box, The Flasher, Beeping Tom, Happy Honker, and Harvey Wallbanger. The robots have both productivity and personality, a combination that is necessary if they are to be successful with the people they work with. □

Noteworthy System

The ability of an ASEA industrial robot to work with high precision under repetitive and arduous conditions was demonstrated during a "musical exhibition" at La Suede Fantastique, a Swedish variety show held at Olympia in Paris. The ASEA IRB 6 industrial robot played a number of synthesizers set up as an "orchestra," enabling the audience to see its unique precision capabilities utilized in strenuous and exacting circumstances. ASEA's U.S. Industrial Robot Division is located at 1176 East Big River Road, Troy, Michigan 48084, Tel. (313) 528-3630.



Continued from page 12
quences of the present revolution in laborsaving technology."

Systems and Software *October, 1982 pp. 17-19.*

An article in *Systems and Software* points out the increasing use of knowledge-based systems by major vendors, such as Tektronix, RCA, Lockheed Engineering Management Services Company, and Texas Instruments. The article states that Xerox Corporation is expanding its efforts in scientific processors for artificial intelligence.

David Birch of MIT feels that one problem with the artificial intelligence discipline is that it tends to focus only on problems for which it can find "elegant solutions." Mr. Birch directs attention to the branch of artificial intelligence that deals with "large, fuzzy problems for which there may be no clear solution." One way to apply computers to these very large problems is to harness the power of many processors connected in parallel.

New York Times, Careers '83 *October 1982, p. 5.*

"Retraining Workers Becomes A Priority" is an article about the growing national need for worker retraining programs. The article suggests that: "There is a dramatic structural change in the economy. About 9 of every 10 new jobs created are service or technical in nature and represent skills." The article covers the trend of dislocated workers and points out the mismatch between the skills of American workers and the available jobs.

Datamation *October 1982, p. 14*

According to *Datamation,* MIT professor Marvin Minsky is working on a large computer system. The computer is expected to use about one million microprocessors configured in an array which simulates neural connections within the brain. According to the article, Minsky and his colleagues are "looking for a semiconductor firm to help them out in designing and manufacturing 16,000 VSLI chips that would each contain 64 sample processors." Each processor, in turn, would have a small amount of memory. If built, the machine may help Minsky test his theory that the brain has evolved into a loosely organized group of thought processes, not one of which dominates the brain's operation.

READER SERVICE

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23	University of California, p. 9

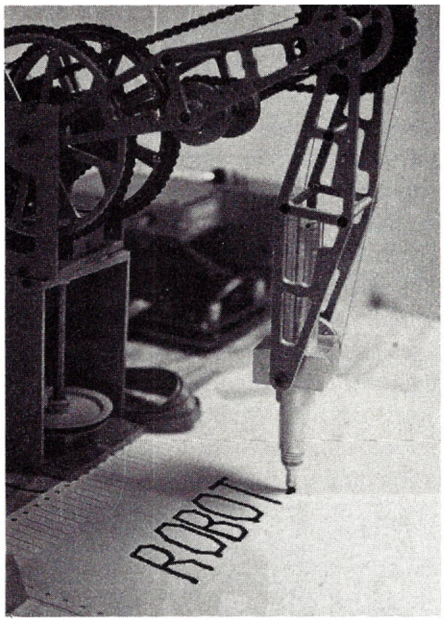
*correspond directly with company

TEACHING THE RHINO XR-1 TO WRITE

Jorg Jemelka
Digital Computer Lab, Room 53
1304 West Springfield Avenue
Urbana, Illinois 61801

Sandhu Machine Design and Vertel Incorporated, recently consulted the Robotics Group at the University of Illinois at Urbana-Champaign on the development of a system, based on the Rhino XR-1, which would generate written output, translating the ASCII character set into an alphabet for execution by the Rhino. The project specified that characters were to be approximately two inches high with a 20-character line width. The development of the end-effector was relegated to the facilities at Sandhu, while the control scheme would be developed by the Robotics Group.

The first several weeks of the project consisted of a feasibility study with a limited alphabet and focused primarily on enhancing the Rhino's reliability. The host computer was the North Star Horizon which was already used to control the Rhino. Existing software, written in North Star BASIC, was used to transform xyz coordinates into Rhino step sequences.



Rhino Modifications. The Rhino is powered by servomotors and provides feedback from motor-mounted encoders. A step is defined as one-sixth of a motor revolution, and the motors have a built-in 65-to-1 reduction. Further reduction is produced by gears between the motors and the joint being controlled.

Commands to the Rhino are in the form of ASCII strings communicated serially by an on-board Intel 8251 ACIA. The first character of the command string is a motor code (ASCII A..G). The second is an ASCII direction code (+ or −). The rest are the individual digits of the step count. The steps issued to a given motor can range from 0 to 127, since the feedback registers on the Rhino's Intel 8748 control processor use the high-order bit as a direction flag. Step commands larger than 127 drive the motors in the reverse direction intended, for the number of steps in excess of 127.

Goals of the project included repeatability on the order of 1/10 of an inch and preventing a command sequence from being *swallowed* by the Rhino. To ensure the reliable receipt of command sequences, the interrupt line from the Rhino's 8251 ACIA (pin 14), is fed back to pin 20 of the RS-232-C connector to serve as a clear-to-send (CTS) signal for the host computer. This signal (inverted) inhibits the host from transmitting a character while the Rhino is busy processing an earlier command character.

Positional repeatability is enhanced with the addition of a *hard home* position. The limit switches on the Rhino are relocated to provide an unambiguous initial state for the manipulator and to simplify the implementation of a single-step home routine. The limit switch for the shoulder is mounted high on the base of the Rhino, locating the shoulder 45 degrees to the rear. Moving the switch to the base, where it is activated by shoulder contact, provides the advantage that if the switch is not closed (on) the only search direction is up (ASCII '—'). A closed switch means the arm is in the home position.

The unmodified limit switches are actuated by cams mounted on the large gears which drive the various axes. A search strategy using these cams must consider that the cam may be above or below the limit switch. Should the search in either the plus or minus direction be unsuccessful (should the joint collide with the body) before the switch is closed, this "stuck" condition must be detected, and the search direction must be reversed.

The cam profile creates a "dead" zone of some 60 to 80 steps, further complicating the definition of a home position. Mounting the limit switches so that they are activated directly by the driven joint ensures that the home position can be defined to within a single encoder step.

The elbow limit switch is mounted on the shoulder and is closed when the elbow joint just makes contact with the shoulder joint. In this case, either the switch is closed and the elbow is *home*, or the elbow must be driven in the minus direction towards its home position. The base limit switch is mounted so that it is closed when the base rides over it. In this case, if the switch is closed, the Rhino moves in the plus direction until the switch is open. If the switch is open, the Rhino moves in the

opposite direction until the switch is closed and then reverses until the switch is open again.

There are cases in which the base strategy fails, but these require a base error in excess of 45 degrees (300 encoder steps). This amount of error is unlikely. The base home position is "edge sensitive." It provides a considerable enhancement of positional accuracy relative to the actuating cam normally provided, since it eliminates the cam dead zone and the attendant complication of searching out the plus and minus cam limits.

Writing. A provisional writing capability was first improvised by the removal of the finger assembly and its threaded open/close shaft. The hollow shaft which provides finger rotation was used to hold an ordinary ball-point refill and was spring-mounted on the hand assembly to provide approximately 25 millimeters of spring travel. The tolerances between shaft and refill were close enough to allow free movement and reasonable pen stability.

The control strategy consists of two parts. The first part moves the motors from home to the first character coordinate, driving the motors the number of steps required at full speed without consideration for coordinated joint movement. This same uncoordinated approach moves the manipulator from the end point of one character to the starting point of the next. A second strategy is employed while actually tracing out the individual letters. To produce coordinated joint movements, the servomotors are driven one step at a time. The use of the individual step-sensing capabilities of the encoders obviates the need for speed control in coordinating the various joints and reduces the control problem to a form suitable for solution using digital difference analyzer (DDA) algorithms.

DDA algorithms are commonly encountered in computer graphics when the slope of a line is to be plotted. An example is plotting points on a screen when only integer coordinates are attainable and the y-coordinate may have a fractional component for a given x. In this case, if a line is to be traced from some start xy to some end xy, the base, elbow, and shoulder motors all may play a part in accomplishing the move. The motor with the largest number of steps is used as the *master* and is stepped continuously. The remaining motors are stepped if their total step count, when subtracted from the total step count of the master motor, drops below zero. This subtraction is performed once for every step of the master motor.

When the zero threshold is crossed for any motor, the master motor's step count is added to the negative quantity remaining, the motor is stepped, and the procedure continues until the master motor has no steps remaining. To ensure that the master motor is continuously stepped, the initial quantity from which each motor's step count is subsequently subtracted is one-half the master motor's step count. This procedure provides a zero crossover with each subtraction of the master motor's step count for the master motor and a correct time interval for stepping the remaining motors.

The control algorithm is implemented in Z80 assembly language. Since fine control is needed for only small moves, an 8-bit step count is used, providing a maximum move of 255 steps for any motor in any segment. Care must be taken not to allow the step count to build up in the master motor's command register. A build-up of unexecuted commands results in imprecise coordination of the Rhino's motors. Conversely, reading the master motor's control register and waiting until each step has been executed slows the motors down visibly and results in a speed versus accuracy tradeoff.

To effectively use this "incremental servoing" technique, the characters are divided into segments. A whole segment is defined to be the maximum height (two inches) of the Rhino alphabet. Fractional segments are constants defined as (H)alf, (Q)uarter, and (E)ighth. A whole segment is a 50-millimeter line, with the fractional segments being 25, 13, and 7-millimeter lines respectively. To trace out a letter:

- The manipulator moves from home position to a starting xy position with a z-coordinate ap-

proximately 20 millimeters above the table.

- A flag is set to indicate the incremental servoing mode is in effect.
- The manipulator moves down to a z-coordinate that corresponds to a ½ inch spring loading of the pen.
- Line segments are drawn until the character is completed.
- The incremental servoing flag is reset.
- The pen is moved to a z-coordinate approximately 20 millimeters above the table.
- The manipulator moves to the next character position.

Once the feasibility of tracing reasonable characters was demonstrated, the Robotics Group developed the complete alphabet and numerals, as well as space, dash, and line feed commands.

As the program neared completion, Sandhu Machine Design delivered a pen holder designed for broad-stroke felt pens. This holder is precision-machined from aluminum stock, with a total sprung travel of two inches. The tolerances were close enough that a hole was drilled to vent pressure buildup. The Robotics Group experimented by varying the size of the opening to effect spring damping. The combination of felt pen and spring damping helped to mitigate the staircase effect that was evident in earlier efforts using the ballpoint refill and the standard hand.

Software Character Definition. Each character is a BASIC subroutine that consists of a sequence of xyz coordinates. As each coordinate is reached, the pen traces a line segment. By way of illustration, the subroutine that draws the letter S is shown below.

```
530 X1=N1+E \ Y1=N2-H \ Z1=U \ GOSUB 70 \Z1=D \ GOSUB 70 \ F5=1
531 X1=X1-E\Y1=Y1+E\GOSUB 70\Y1=Y1+Q\GOSUB 70\ X1=X1+E \Y1=Y1+E
532 GOSUB 70 \ X1=X1+Q \ GOSUB 70 \ X1=X1+E \Y1=Y1-E \GOSUB 70
533 Y1=Y1-Q\GOSUB 70\Y1=Y1-E\X1=X1+E\GOSUB 70\X1=X1+Q GOSUB 70
534 X1=X1+E\Y1=Y1+E\GOSUB 70\Y1=Y1+Q\GOSUB 70\ X1=X1-E\Y1=Y1+E
535 GOSUB 70 \ F5=0 \ Z1=U \ GOSUB 70 \ N2=N2-H-E \ Y1=N2
536 X1=N1 +H \ GOSUB 70 \ GOTO 335 \ REM 'S'
```

The variables N1 and N2 are offsets for the x- and y-axes from the base center. N2 is updated at the end of each letter subroutine to reflect the center of the next letter field's x center, and the start of the next letter field's y-coordinate. The z-axis can be either up, U, or down, D.

On entry into the S routine, the pen is set at the top left of the letter S and is set down. The F5 flag is set to indicate that incremental servoing is in effect. The remainder of the letter is traced. The F5 flag is reset and the pen is raised in line 535. The subroutine call to line 70 performs the coordinate to motor step transformations and calls the assembly-language drivers according to the flag setting.

Pen movement is from left to right. The start x is 170 millimeters out from the base, and start y is 240 millimeters to the left of the base. Two successive text lines may be written. Best results are attained if the recommended line width of 20 characters is not exceeded. The program also centers each line of text with respect to the center of the Rhino's base.

The final phase of the project is expected to be the connection of the Rhino to a Vertel magnetic card reader. □

PHILOSOPHY AND THE BIRTH OF COMPUTER SCIENCE

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The genesis of computer science is a fascinating story. It involves people from different eras, of different nationalities, in different professions, with different goals. Surprisingly, perhaps, philosophers were involved directly and indirectly in its development. There are, of course, various ways in which philosophers and computers cross paths. I will mention some of these as I proceed, but mostly, I will be concerned with tracing the influence and role philosophers and philosophy have had on the computer.

Leibniz and Frege. The first philosopher to become involved with a computing machine was Blaise Pascal (1623-1662), the builder of the very first such machine. At the age of 20, Pascal designed and built a machine that could add and subtract. Pascal, however, did not find this philosophically significant in any way. Rather, he seemed to have built the machine as an aid to his father who spent much time on computations.

Gottfried Wilhelm Leibniz (1646-1716), at the age of 27, completed the design and construction of a calculating machine that could add, subtract, multiply, and divide. He invented a device now known as the Leibniz wheel which is still used in some machines. Leibniz shared Pascal's concerns of reducing time spent on calculation. He wrote that "it is unworthy of excellent men to lose hours like slaves in the labor of calculation which could safely be relegated to anyone else if machines were used."

Leibniz had a second hope in what he called Universal Mathematics. He sought "a general method in which all truths of the reason would be reduced to a kind of calculation," in his words, a *calculus ratiocinator*. This last concern is of a distinctly philosophical nature: Leibniz wished to ground, establish consensus on, and secure knowledge by reducing problems to straightforward, mechanical calculations.

These two goals, freeing man from tedium and securing foundations for knowledge, played roles in the development of the computer. The influence of the first aim is certainly more direct than that of the second. The drudgery and difficulty of compiling lunar tables, of doing tidal harmonic analysis (involving the computation of integrals of products), of preparing statistical analyses of the results of a census, and of analyzing the problems of ballistics are just a few examples that quite early on served as stimuli for the development of more and more powerful computing machines. (For more information, consult H. H. Goldstine's *The Computer: from Pascal to von Neumann,* Princeton University Press, 1971.)

The influence of the second goal, though perhaps less obvious, should not be underestimated. The philosopher and mathematician Gottlob Frege (1848-1925) published his *Begriffsschrift (Concept-writing* or *Ideology)* in 1879. Although the book has fewer than 90 pages, it remains the most important work ever published in logic. It was Frege who created logic as it is known and studied today.

Frege's aim was to provide a foundation for arithmetic. He wanted "to provide us with the most reliable test of the validity of a chain of inferences and to point out every presupposition that tries to sneak in unnoticed, so that its origin can be investigated."

Think of programming languages that are, in several ways, descendants of Frege's logic. Frege's logic was perhaps the first language explicitly constructed from a set stock of symbols manipulated according to fixed and precise rules. Frege compared his goal with Liebniz's, writing that

> Leibniz, too, recognized — and perhaps overrated — the advantages of an adequate system of notation. His idea of a universal characteristic, of a *calculus philosophicus* or *ratiocinator,* was so gigantic that the attempt to realize it could not go beyond the bare preliminaries.... But even if this worthy goal cannot be reached in one leap, we need not despair of a slow, step-by-step approximation. When a problem appears to be unsolvable in its full generality, one should temporarily restrict it; perhaps it can then be conquered by a gradual advance.... The ideography proposed here adds a new [realization of Leibniz's idea] indeed the central one, which borders on all the others.... I am confident

that my ideography can be successfully used wherever special value must be placed on the validity of proofs .... (Reprinted in Jean van Heijenoort's *From Frege to Gödel: A Source Book in Mathematical Logic, 1879-1931,* Harvard University Press, 1967.)

Frege saw his work as a central advance towards part of Leibniz's goal of a universal language that could serve unsupplemented by intuitive reasoning as a foundation of our knowledge of mathematics.

Foundations of Mathematics and Hilbert's Program. Frege was one of the first to work on what are called "foundations." More and more attention was paid to foundational studies. The first two decades of this century found mathematicians deeply involved in them. The conflicts between mathematicians' views had become extremely severe, even though many of these divisive issues, especially those of a philosophical nature, had been around for a long time, to say the least. Thinkers had always been struck by the fact that, unlike other kinds of knowledge that we possessed, mathematical truths were not acquired by observing the natural world. It was puzzling, especially for those who believed we acquired our knowledge through experience and interactions with the physical world, how we could ever obtain knowledge about these seemingly abstract mathematical entities.

The mathematical and philosophical communities were divided between two views. One view (platonism) held that mathematical propositions were true or false, independently of our being able to know or determine which. The other view (constructivism) claimed that it did not make sense to speak of some mathematical statement as being true or false, independently of our having the ability to discover which was the case. The views and all their versions differed on their analyses of the natures of mathematical truth, knowledge, and existence. The situation was serious in that their views led some mathematicians to refuse to recognize proofs that did not satisfy certain requirements. Because of differing notions of "legitimate proof," there was actually great division surrounding which statements had been proved and which had not.

The mathematical climate was further exacerbated by several inconsistencies or paradoxes that had been discovered in various foundational systems. Non-Euclidean geometries had been shown to be consistent if Euclidean geometry was, which in turn had been shown to be consistent relative to arithmetic. Foundational work had shown this, in turn, to be consistent relative to set theory. At the turn of the century, paradoxes were found in set theory. The most famous was Russell's paradox that vitiated Frege's proposed system. (This did not affect the *Begriffsschrift.*)

David Hilbert, one of the great mathematicians of this century, attempted to set mathematics' house in order. He devised a plan, often called *Hilbert's program,* that, had it been successful, might have cleared up many of the philosophical problems that plagued his profession. His program called for dividing mathematics into two parts, the *ideal* part and the *real* or *finitistic* part.

Finitistic mathematics contained those statements about which Hilbert claimed one could uncontroversially speak of being true or of being knowable by us. Ideal statements of mathematics, which included those portions over whose validity there was so much disagreement, were not, like most statements, either true or false. They were contentless sequences of signs about which it made no sense to say "We know/don't know this." Rather, Hilbert wanted to show that they functioned as simplifying tools in our overall mathematical theory. Whatever mathematically meaningful statement we could have proved using the ideal part of mathematics could have been proved using only the finitistic part.

Although ideal mathematics might be heuristically useful and certainly allows for shorter proofs, it is, in principle, eliminable. (Perhaps a germane analogy would be to compare higher-level programming languages with machine languages. In principle, all programming could be done in machine language, though at a cost of length and suggestiveness. Higher-level computer languages must ultimately be "cashed out" in terms of machine language, though working with them simplifies programming.)

To explain in detail how Hilbert wanted to accomplish this would take us too far afield. It suffices for our purposes to note that it involved using the real part of mathematics to prove the *consistency* (for no formula F can one prove F and prove the negation of F) and the *completeness* (for every formula F, either F is provable, or the negation of F is provable) of ideal mathematics.

This project occupied many minds in the 1920s. In 1929, John von Neumann was busily engaged in trying to prove the consistency of a certain branch of mathematics.

Gödel. In 1931, Kurt Gödel (1906-1978) announced two results which are unequalled in influence on the course of mathematical logic. They also played a central role in the development of theoretical computer science. They showed, however, the impossibility of realizing Hilbert's program as then formulated. Gödel's first result (actually J. B. Rosser's 1936 strengthening of Gödel's result) was that if a sufficiently powerful mathematical system was consistent, then it was incomplete; that is, there would be a formula (in fact, a true formula) which was neither provable nor refutable in that system. Gödel's second result (again, Rosser's extension) stated that if a sufficiently powerful mathematical system was consistent, then it (and, of course, all weaker systems) could not prove its own consistency. The mathematical world, which had been waiting for the opposite results, was shocked but rapidly accepted Gödel's proofs. Though Gödel's proofs were ingenious and dealt what many thought was a death blow to Hilbert's program, only two ideas proved important for the development of computer science.

The first idea is the device known as *godel-numbering.* The idea is to code unambiguously the formulas of formal systems into the natural numbers. A simple example is the following.

Imagine our formal system to consist

of the formulas built up using '+', '$\times$', '=', '(','),' 'a', 'b',..., 'z', 'a''', 'b''', and so on by means of the usual rules of the language of arithmetic. Thus all of '$(a + b) = e$', '$(((d+d)\times(g+z))\times p) = d$', '$e = r$' are formulas of this language whereas '$a+k$', and '$j+i \times l = e$', '$(b-2)=a$' are not. Let the godel-number, as it is called, of '+' be 1, of '$\times$' be 2, of '(' be 3, of ')' be 4 and of '=' be 5; and let the godel-number of 'a' be 6, of 'b' be 7, and so on. Each symbol in the language is assigned one and only one number.

How do we extend this assignment to formulas? One way (Gödel's way) is as follows: the godel-number of a string $x_1x_2\ldots x_n$ is $2^{g(x_1)}\cdot 3^{g(x_2)}\cdot \ldots \cdot Pr(n)^{g(x_n)}$ where $g(x_i)$ is the godel-number for the symbol x_i, and where $Pr(i)$ equals the ith prime number. For example, the godel-number of '$(a+c)=f$' is $2^3\cdot 3^6\cdot 5^1\cdot 7^8\cdot 11^4\cdot 13^5\cdot 17^{11}$ — quite a large number! The godel-number of '$a = ($' (not a formula of our language!) is $2^6\cdot 3^5\cdot 5^3$.

The important point is that every string of symbols of the language (and hence all formulas) can be represented by a number that, though perhaps quite large, is calculable. The converse is true as well: every number can be viewed as representing some string of symbols of the language. This is true in virtue of Gauss's theorem that every number greater than 1 has exactly one decomposition into powers of prime factors. For example, 243,000,000 equals $2^6\cdot 3^5\cdot 5^6$ and hence represents the formula '$a = a$'; whereas 3456 equals $2^7\cdot 3^3$ and thus represents the non-formula '$b($'.

It is important that every formula has one and only one computable number correlated with it and that each number represents at most one formula which, if it exists, is effectively determinable. This shows that, theoretically, computing machines that are restricted to numerical computations could operate in other symbolic domains by a suitable "godelization." Later in this article, we will see an abstract model of a "universal machine" — one that can perform all effective computations — that operates solely on numbers represented in a certain manner.

Gödel's second original contribution is particularly important for theoretical computer science. This is his definition of *primitive recursive functions.* Gödel was one of the first to give a formal characterization of this class of functions; furthermore, his definition has become the standard one. According to the definition, one states the notion of one number-theoretic function (one whose arguments and values are numbers) being defined in terms of other such functions by *composition.* In general, the n-place function $f(x_1, \ldots, x_n)$ is said to be obtained from the composition of the m-place function $h(x_1, \ldots, x_m)$ and the m n-place functions $g_1(x_1, \ldots, x_n), \ldots, g_m(x_1, \ldots, x_n)$ if $f(x_1, \ldots, x_n) = h(g_1(x_1, \ldots, x_n), \ldots, g_m(x_1, \ldots, x_n))$.

For example, the function $f(x) = x^3 - x^2 + x$ is obtained by composition of the functions $h(x_1, x_2, x_3) = x_1 - x_2 + x_3$, $g_1(x) = x^3$, $g_2(x) = x^2$, and $g_3(x) = x$, since $f(x) = h(g_1(x), g_2(x), g_3(x))$. Next, Gödel stated how to define one function in terms of others via the means of *primitive recursion.* In general, the n-place function $f(x_1, \ldots, x_n)$ is said to be obtained by primitive recursion from the $n-1$ place function $g(x_1, \ldots, x_{n-1})$, and the $n+1$-place function $h(x_1, \ldots, x_{n+1})$ if $f(0, x_2, \ldots, x_n) = g(x_2, \ldots, x_n)$ and $f(k+1, x_2, \ldots, x_n) = h(k, f(k, x_2, \ldots, x_n), x_2, \ldots, x_n)$.

The intuitive idea is to define a function for the value 0 and then, in general, define it for k in terms of its value for $k-1$. If we now call the *basic* functions the successor function ($f(x) = x+1$), the identity function ($f(x) = x$), and all the constant functions ($f(x) = c$, for some constant c), then we are in a position to define the class of primitive recursive functions: a function f is primitive recursive if there is some sequence of functions whose last member is f each member of which is either basic or obtained from previous members of the sequence by composition or primitive recursion. Intuitively, the primitive recursive functions are built up from the basic functions by means of composition or primitive recursion. A few examples should bring this all home.

Consider the two-place function $A(x,y) = x+y$. Since $A(0,y)$ $(= 0+y)$ is equal to the basic function $g(x) = x$, and since $A(k+1,y)$ $(= (k+1)+y)$ is equal to the composition of the successor function with $A(k,y)$ (i.e. $A(k+1,y) = 1 + A(k,y)$, $(k+1)+y = 1+(k+y)$), we see that addition is primitive recursive. Once we have established this, we can show that multiplication is primitive recursive. Let $M(x,y) = x\cdot y$; then $M(0,y)$ is equal the value of the constant function $g(x) = 0$ and $M(k+1,y) = A(M(k,y), y)$ (since $(k+1)\cdot y = (k\cdot y)+y$). As a final example, let us look at the factorial function $F(x) = x!$. Since $F(0)$ is equal the constant function $g(x) = 1$, and since $F(k+1) = M(k+1, F(k))$, the factorial function is indeed primitive recursive.

These are only a few of the marvels that are contained in Gödel's epoch-making paper. It would, unfortunately, take us too far afield to go into it in any more depth or breadth. Gödel's results served as an answer (definitive according to some) to an important attempt to secure a foundation for our knowledge of mathematics, Hilbert's program. Although Hilbert was a mathematician, he launched this program (unformulable without Frege's contribution to the development of logic) in an attempt to lay to rest philosophical doubts that had recently come to plague mathematicians and philosophers. It is ironic that Gödel's results, so destructive to philosophical attempts to come to terms with mathematics, would be so instrumental in the development of theoretical computer science.

Algorithms, Church and Turing. For many years, mathematicians had been working with the informal notion of an effective computation. In the revealing intuitive rendering, an effective computation is one that a machine could be made, or programmed, to do. The "could" here is not "could in practice" but rather "could in principle." The computation involved in determining whether a given opening move of a chess game is a winning move is right now beyond the limits of even our most powerful computers. And yet the calculations are effective, that is, in principle they could be carried out. In other words, there is an algorithm for determining whether, say, P-K4 is a winning move.

There was never any disagreement when a mathematician proved that something was effectively calculable,

because this would consist in exhibiting an algorithm that would do the job. Why, then, was a formal characterization sought? One reason was that, without such a general characterization, no study of the notion of effective computation itself was possible. If all one had were particular examples of effective computations, one could not prove theorems that held for all such computations.

A second reason was that, without such a general specification, one could never prove that something was *not* effectively computable. One could show that, for some problem, *this* particular algorithm would not work, nor would *that* one, but without a general characterization, mathematicians were unable to prove that no algorithm at all would work.

The basis for this formal specification of effectively computable functions was the class of primitive recursive functions. This class, however, did not admit all functions that were intuitively computable.

The class of functions that became the candidate for the class of computable ones was obtained from the class of primitive recursive functions by closing it under the operation of *minimization.* For the curious, an $n-1$-place function $f(x_1, \ldots, x_{n-1})$ is obtained by minimization from the n-place function $g(x_1, \ldots, x_n)$ if $f(x_2, \ldots, x_n)$ is equal to the least y such that 1)$g(y, x_2, \ldots, x_n) = 0$ and 2) for every $z<y, g(z, x_2, \ldots, x_n)$ is defined; $f(x_2, \ldots, x_n)$ is undefined otherwise. The class is closed under minimization if application of that operation to a member of the class yields a member of the class. The class obtained in this manner is known as the class of (partial and general) *recursive functions.*

The position that holds that a function is effectively computable if and only if it is recursive was formulated in 1936 by the American logician Alonzo Church and is known as *Church's thesis.* It is a thesis about what the proper formalization of the intuitive notion of effective computability should be. When one remembers that computers are machines designed to carry out (ideally) all effective computations, one realizes that Church's thesis marks the beginning of the mathematical study of the capacities of computers. Theoretical computer science was about to be born.

It is Church's *thesis*, not Church's *theorem.* There is no question of *proving* Church's thesis since it relates an intuitive notion, effective computability, to a mathematical notion, the class of recursive functions. Mathematical theorems can only relate one formal notion to another. We could stipulate that the effectively computable functions are to be identified with some class C of mathematical functions and then attempt to prove that C is identical to the class of recursive functions. But then we are left with another *Church's thesis* that cannot be proved: the relation between the formal object C and the intuitive notion of effective computability.

If proof is out of the question, why should one accept Church's thesis? There are three basic reasons. The first is that, though proof is not possible,

disproof certainly is. If Church's thesis was false, then either we could find a function that was not intuitively computable even though recursive or we could find a function that was intuitively computable though not recursive. To date this has not happened. No counterexamples of these kinds have ever been reported.

The second reason is that, over the years, mathematicians and logicians have advanced many different proposals for the formal characterization of effective computability. It has been proved that every one of these characterizations picks out the same class of functions. It seems that this class of functions forms a mathematical natural kind. The formal characterizations of this class have been extremely varied. We saw one historically important example in the notion of recursive functions. There is another specification advanced by the British mathematician Alan Turing in 1937 that will not only serve as a good illustration for the third reason for accepting Church's thesis, but also represents the beginnings of theoretical computer science or automata theory. This is the *Turing machine.*

This abstract machine can be in any of a finite number of states. It operates on a tape of infinite length subdivided into cells. On each cell, either '0' or '1' is printed. The machine can make the tape move one cell to the left or one cell to the right, scanning one cell at a time. When it scans a cell, it has the option of printing '0' or '1', moving the tape left or right, and changing states. The state the machine goes into is determined by the state it is in and by the entry of the cell it is currently scanning. The instructions to the machine can be viewed as a set of ordered quintuples of the form <<state1>, <entry>, <print instructions>, <motion instructions>, <state2>>. This means: when in the state specified by the first member of the quintuple, scanning the entry given by the second member ('0' or '1'), then perform the print instructions given by the third member (print '0' or print '1'), move according to the instructions given by the fourth member (move one left, one right, or do not move), and, finally, go into the state specified by the last member of the quintuple (possibly equal to the first member of the quintuple). Inputs are represented by a string of unbroken '1's on the tape. The machine is started in some arbitrarily designated starting state and is positioned to scan the left-most occurrence of '1' on the tape. The machine then "computes." It either halts or does not. If it halts, the configuration of '0's and '1's on the tape either represents a number or does not. In this way, we can view the machine as a function (perhaps a partial one, that is, one not defined for all arguments). In fact, every Turing machine can be viewed as a recursive function. The converse is also true. Every recursive function is computed by some Turing machine. This is a restatement of the second of three grounds for holding Church's thesis: the class of functions that are recursive is identical to the class of functions that are Turing computable. This gives us another version of Church's thesis: a function is effectively computable if and only if it is Turing computable.

The Turing machine is an abstract version of the modern computer. It might be thought that each Turing machine can compute only one function, whereas a computer can compute any number of functions because it can be programmed in any number of ways. Turing, however, proved that there exists a universal Turing machine in the sense that this single machine can mimic the computational behavior of all Turing machines. It is, in a sense, all Turing machines rolled into one.

One might recall Leibniz's anticipation of the day when all the truths of reason could be churned out by some device. If we accept Church's thesis, then a problem is effectively computable if and only if it can be calculated by the universal Turing machine. Is the universal Turing machine a modern *calculus ratiocinator*? I will leave these questions to the Leibniz scholars.

One might still be skeptical. Modern computers, after all, have so many features that this Turing machine lacks. Memory is an important one. It might be thought, if we were more liberal in our description of Turing machines, say, by allowing them a second tape for "scratch," or by giving them more freedom in movement, or extra symbols that they could print or read, then we would get a larger class of functions that are Turing computable. This is not the case. None of these or other reasonable extensions of the notion of a Turing machine enlarges the class of Turing computable functions. Indeed, this is the third ground for affirming Church's thesis: the class of functions in question seems to be closed under reasonable extensions of the various formal means used to specify it.

In this connection, it is well to recall "godelization." The Turing machine reads and writes configurations of only '0's and '1's. These can be viewed as representations of numbers. Given the "godelizability" of formal systems, (their encodability into the natural numbers), Turing machines need deal with no more than numbers under some representation.

There are, then, no computations that a modern computer could perform that could not be carried out by the simple abstract construct of the Turing machine. For this reason, Turing machines and related constructs have been the focus of investigation into the capacities of the modern computer and have been essential in attaining a deep understanding of the nature of these machines.

It would be a mistake to think that the study of Turing machines, in particular, and automata, in general, has had no practical consequences. In the early 1950s, von Neumann, who had been deeply involved in foundational studies more than 20 years earlier, was investigating the problem of how to organize a machine with parts that can malfunction. Increasing the reliability of a machine constructed from unreliable parts was, and still is, of great practical importance. Studies of formal automata were instrumental in achieving understanding of, and the ability to cope with, the problem of reliable computation in the presence of noise.

Applications were not limited to those involving the computer. In the late 1940s, inspired by the work of McCulloch and Pitts on a formal representation of nervous activity, von Neumann began working on the problem of how complex an automaton had to be in order to be self-reproducing.

Automata theory, then, can be viewed as aiding in the modeling of neurophysiolgical phenomena. Von Neumann saw the many interconnections between automata theory, logic, and computers (some of the historical ones have been sketched here), and this no doubt played some role in his interest in the subject.

Concluding Remarks and Ironies. The computer is now found everywhere. It has made its mark on, and stimulates discussion in, virtually every field. Philosophy is no exception. For the past 30 years, debate over whether man is a machine has been renewed. With the phenomenal development of the computer, another question is raging: Could computers think?

The development of the computer allows new and more precise formulations of these and other questions: What is the nature of the mind? How is the mind related to the body? What is consciousness? What is thought? What is it to understand a language? These debates have not only stimulated philosophers but also have given birth to an entire field of inquiry, artificial intelligence, which has in its turn become philosophical fodder.

The advent of computers has also stimulated philosophical questions outside "the philosophy of mind." Recently, a computer was used for the first time to prove a mathematical theorem, the famous Four-Color Conjecture, that had eluded some of the greatest mathematicians for hundreds of years. The computer was needed to establish a crucial lemma involving computations so great as to prohibit any person from carrying them out. Unlike proofs of the past, the proof was unsurveyable. A debate erupted in the philosophical community about whether the computer had changed the nature of mathematical proof, truth, and knowledge. In this way, according to some, the philosophy of mathematics itself has been touched by the computer.

We began by noting in some measure Leibniz's and Frege's concerns to place our knowledge in general, and mathematical knowledge in particular, on a firm foundation. This hope was at its highest while the best minds in mathematical logic were working on Hilbert's program. It was quickly dashed by Godel's monumental paper which, though devastating, was rich at the same time. Church and Turing seized on it and, independently, laid the foundations of modern computer science.

The computer has greatly aided our understanding of the world; yet it has also fueled the flames of doubt concerning the nature of this understanding. Though the computer was a product of mankind's wish to extend its knowledge while reducing the tedium involved, it was also a consequence of the desire to understand the nature and foundations of this knowledge. It is ironic that the computer now adds to the perplexity that gave rise to this desire in the first place. The goal of erecting a firm foundation for our knowledge has resulted, indirectly, in more questions as to its nature and ever more uncertainty. □

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ERROR REPORT

On page 19 of the November/December 1982 issue, we mistakenly credited NASA for photo 4. Credit should have gone to *Robotics Today* Magazine.

THE 2-ROLL GRIPPER

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417 Grand Avenue
St. Paul, Minnesota 55102

The development of industrial robot grippers, the hands of the robot, is an important part of the advancement of industrial robots. The goal of this article is to disclose a new, more dexterous 2-Roll Gripper concept. I will discuss two common grippers and two more esoteric grippers styled after the human hand and give an operational description of the 2-Roll Gripper. Also included are plans for making a model of the 2-Roll Gripper.

One of the most important features of the human hand is its ability to pick up and rotate small, differently-shaped objects. This task is performed routinely countless times each day by production workers who pick parts out of a bin or off a conveyor belt, even though the part may be upside-down or otherwise disoriented. The worker analyzes the handheld part's orientation and uses the eyes and brain to direct the fingers to rotate the part to the proper attitude for assembly.

The 2-Roll Gripper simulates the human fingers' ability to roll a variety of small parts to a particular attitude. Potential applications include assembly tasks such as picking parts out of bins or off conveyor belts, reorienting the part, and then fitting it accordingly. A screwdriver, nutdriver, or any similar small tool that requires rotary motion for operation may be driven by the gripper without modification of the tool or the gripper.

Gripper Technology Background. The sliding finger gripper (photo 1) gets its name from the action of the fingers. The fingers are usually actuated by an air cylinder in the base of the gripper. The fingers move in a horizontal plane and remain parallel to each other. The pivoting finger gripper (photo 2) also is usually actuated by an air cylinder in the base of the gripper. The fingers, however, pivot with each digit swinging outward or inward in an arc.

One of the many grippers designed to resemble the human hand is shown in photo 3. Cables actuate the three multi-jointed fingers. The cables are powered by electric motors in the base of the gripper. This design suffers from cable stretching, which eventually causes loss of precision. Articulated fingers are difficult for robot computer vision systems to control and direct. They require complicated programs to produce any useful gripper motion.

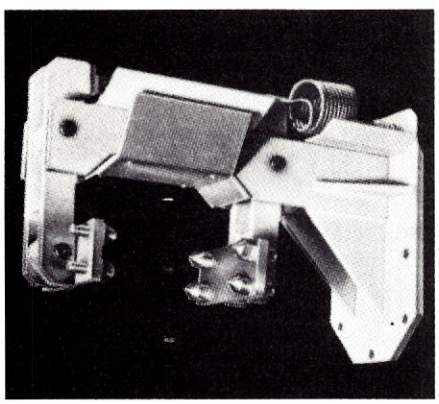

Photo 1: A sliding finger gripper. Photo courtesy of Cincinnati Milacron.

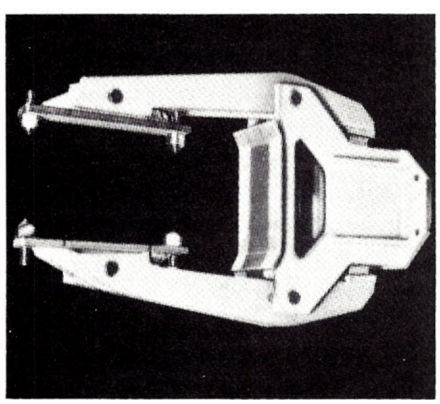

Photo 2: A pivoting finger gripper. Photo courtesy of Cincinnati Milacron.

Photo 4 shows another variation of a gripper designed to resemble the human hand. This gripper uses linkages to communicate power from a hydraulic actuator in the base of the gripper to the fingers. The linkages driving the multi-jointed fingers overcome the problem of cable stretching, enhancing the gripper's mechanical integrity. Directing the fingers to roll a small object to a particular attitude, however, should be a difficult problem for the robot's computer vision system to control.

Description of the 2-Roll Gripper. My 2-Roll Gripper (photo 5) consists of two fingers which are, in this model, designed to slide together for gripping but could also be designed to pivot. To rotate small objects, each finger has a built-in rubber conveyor belt which is driven by a low-speed, high-torque electric motor in the base of the finger. A pulley at the top and another at the bottom of the gripper hold the belt. The lower pulley is driven by the electric motor by means of a small drive belt which goes from the motor to another pulley attached to the bottom conveyor belt pulley.

A spring-loaded idler pulley maintains a constant tension on the belt and provides compliance, or give, to the conveyor belt. The rubber conveyor belts have rubber ribs attached to their outside surfaces to aid in traction with gripping and rotating objects.

The gripper is first positioned over the object to be rotated by the robot (photo 6) and then is lowered by the robot onto the object, in this case, a box lid (photo 7). The fingers are advanced to grip the box lid and then are raised. To bring the box lid into the center of the fingers, both of the fingers' conveyor belts are rotated. The left conveyor moves counterclockwise, the right clockwise (photo 8). To attach the box lid to the box, the lid must rotate 180 degrees. The left and right fingers' conveyor belt is driven clockwise (photos 9-12). Once the box lid is rotated 180 degrees, it is moved to the fingertips by rotating the left conveyor belt clockwise and the right counterclockwise (photo 13). When the box lid is almost out of the gripper's fingers, the gripper is lowered. The box lid is now on the box (photo 14).

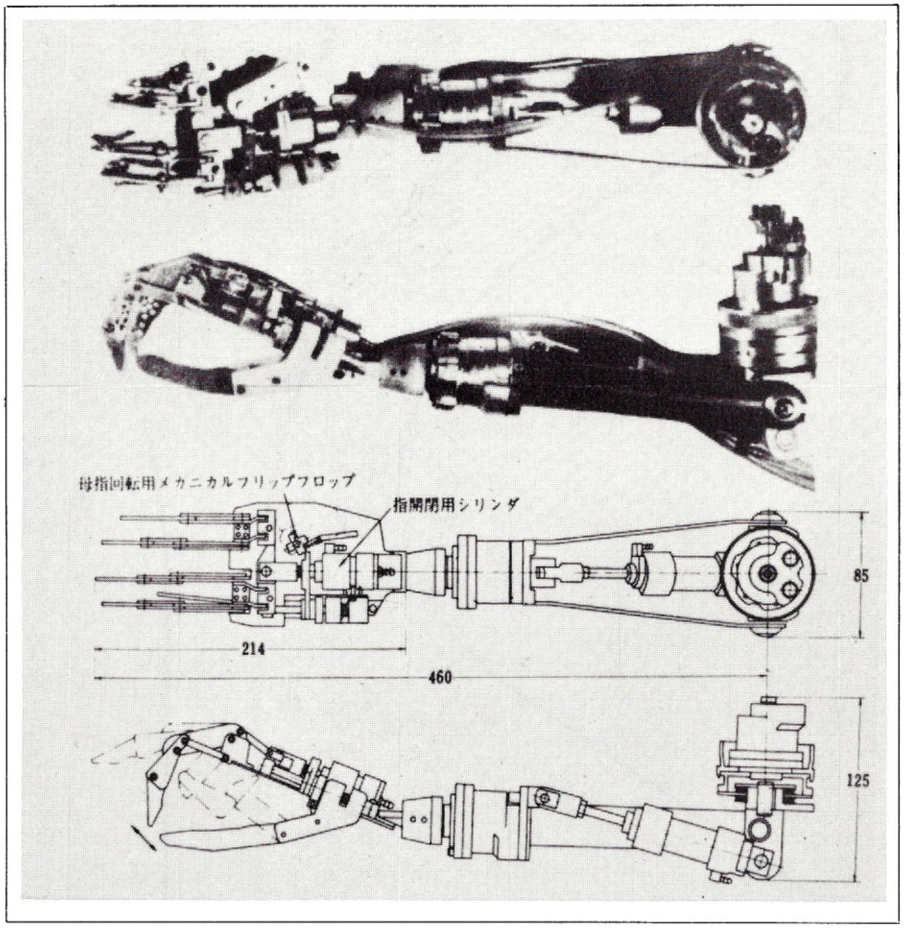

Photo 3: A cable-driven gripper styled after the human hand. This hand was developed by the Automatic Control Division of the Electrotechnical Laboratory of Japan. Photo taken from *"Robots: Fact, Fiction and Prediction."*

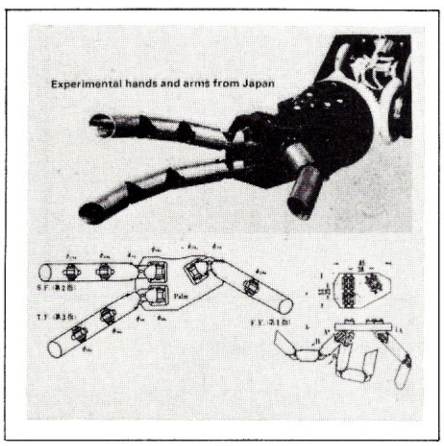

Photo 4: A linkage-driven gripper styled after the human hand by the Mechanical Engineering Laboratory of Japan. Photo taken from *"Robots: Fact, Fiction and Prediction."*

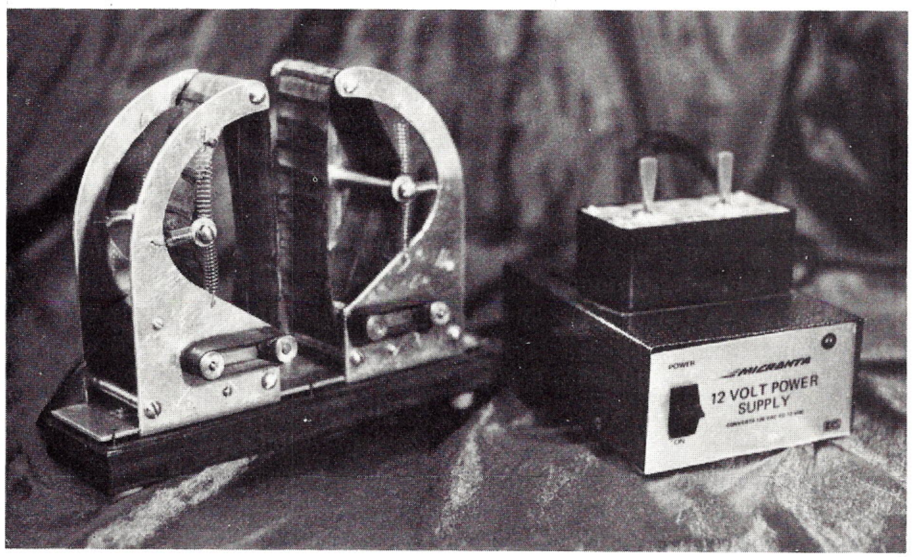

Photo 5: A model of the 2-Roll Gripper with control box and power supply. (2-Roll Gripper photos by Lee O. Grimm.)

The front and back finger plates (figures 1 and 2) are cut out of $^1/_{16}$-inch sheet aluminum with a metal cutting bandsaw. The radii are finished with a small grinding wheel. Each finger plate's bottom has a 90-degree tab formed by clamping the plate in a vise with about $^3/_8$ inch protruding from the jaws. Hammer the protrusion into a tab. These tabs engage the base track to guide the fingers in their sliding motion. The finger track is cut from $^1/_{16}$ inch sheet aluminum on a bandsaw and is attached to the base by two wood screws. Washers on the screws separate the track from the base.

The pulleys (photo 15, foreground) may be made out of brass, aluminum, plastic, or wood. The motor pulleys and drive pulleys have sandpaper glued to them to aid in traction of the rubber belts (photo 1).

Cut up a bicycle inner tube to make the gripper conveyor belts and drive

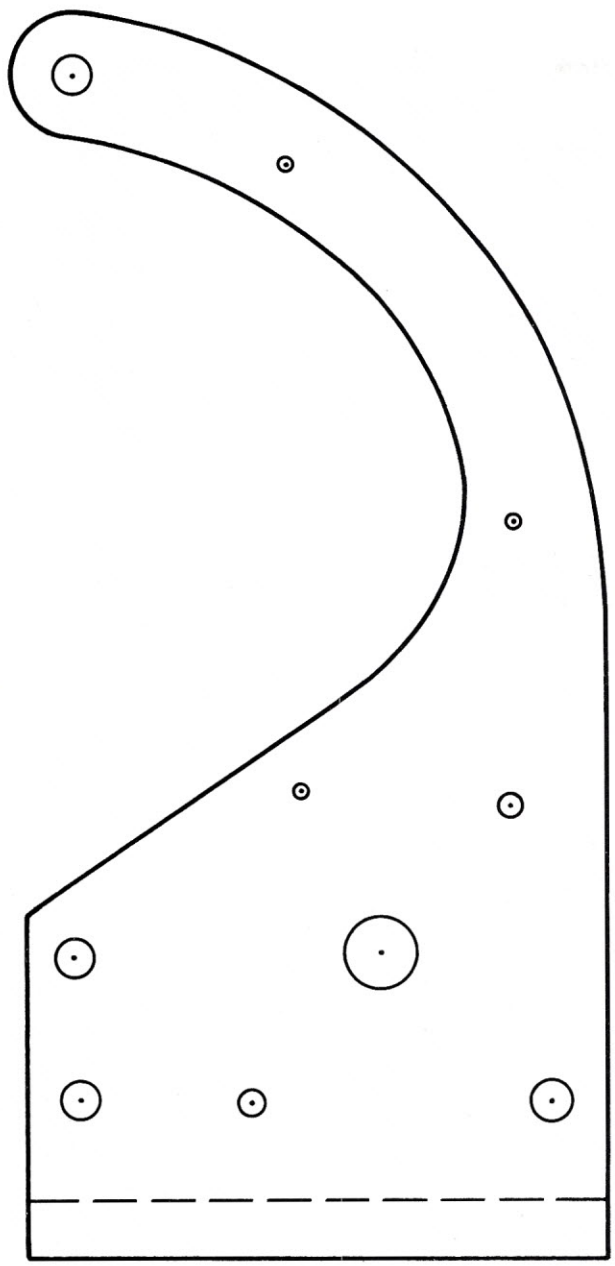

Figure 1: Template for the front finger plate.

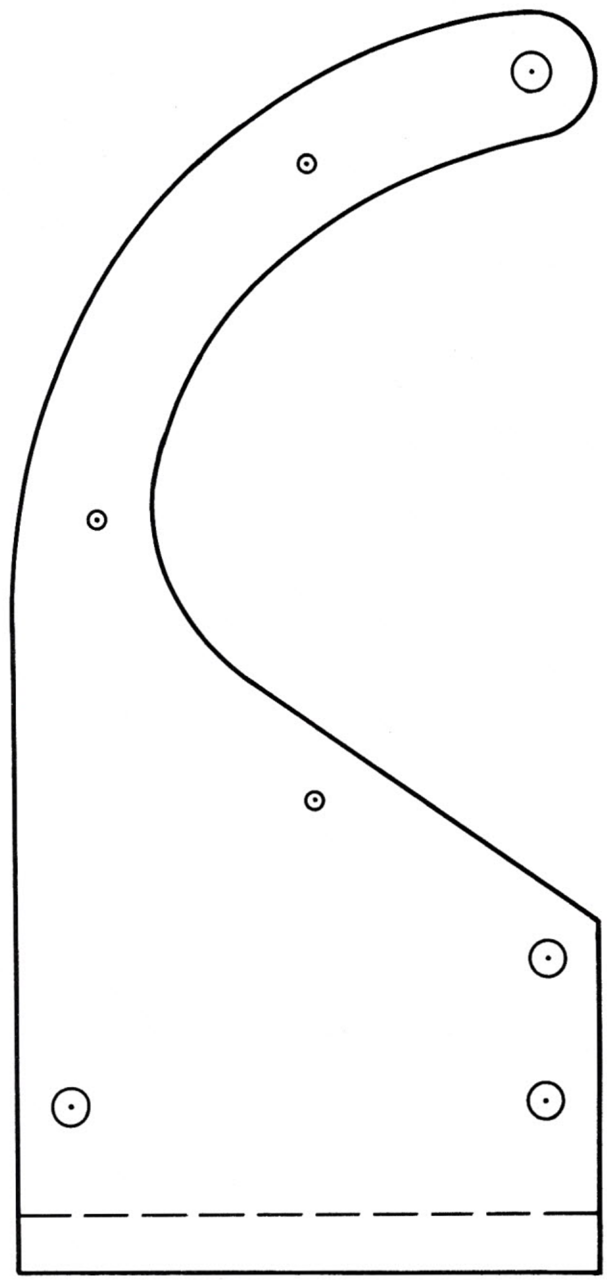

Figure 2: Template for the back finger plate.

belts. One of the quick-setting "super" glues is best for gluing the belt ends together. You can cut the rubber ribs on the conveyor belts from a bicycle inner tube and glue them to the conveyer belts. The springs can be found in a well-stocked hardware store or small parts company. A 120-piece spring assortment is available from Edmund Scientific.

The tube spacers are cut from automobile gas line tubing. Two are used near the base of each finger and at the top, in the pulley, to separate the finger plates. Machine screws through the plates and tube spacers hold the plates together.

The electric motors are attached to the front plate by two small machine screws. Standard lamp cord wire is soldered to the motor terminals for connecting to the power supply. The test controls are two double-pole, double-throw (DPDT), neutral, center-off switches. These are wired for use as forward/reverse switches (figure 3) and are mounted in a small box with a terminal strip attached for making connections to the switches, power supply, and gripper.

To drive the motors a 12-volt power supply is ideal. Fasten the motors to the front plates with the nuts and machine screws. Mount the pulleys and spacer tubes between the plates. Attach the two plate pairs with the machine screws. Fasten the track to the base board and slide the two fingers onto the track. Some filing may be necessary to make the fingers slide freely on the track. Small nails are used for mechanical stops to control the finger

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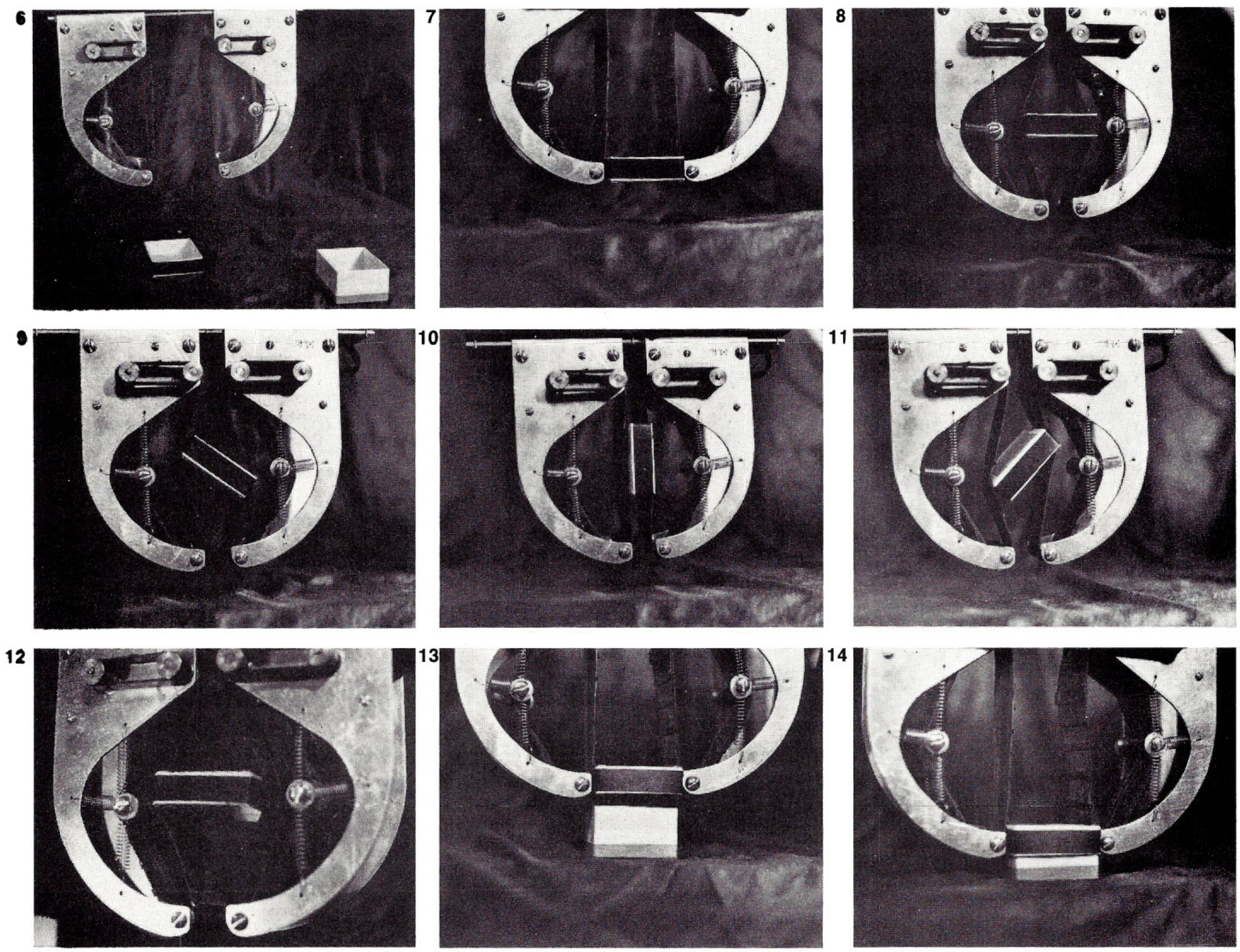


Photos 6-14: The 2-Roll Gripper is positioned over the box lid (photo 6). The gripper is lowered onto the box lid. It grips the lid and raises it (photo 7). The box lid is pulled into the center of the fingers by rotating the left conveyor belt counterclockwise, and the right conveyor belt clockwise (photo 8). To rotate the boxlid 180 degrees, both conveyor belts are rotated clockwise (photos 9-12). The box lid is moved to the ends of the 2-Roll Gripper's fingers to put the lid into assembly position by rotating the left conveyor belt clockwise and the right conveyor belt counterclockwise (photo 13). The gripper is lowered, and the lid is placed on the box (photo 14).

travel.

There are many ways to actuate the fingers for gripping. One simple way is to drive each finger with a solenoid (figure 4). Other ideas include driving the fingers with air cylinders or electric motors.

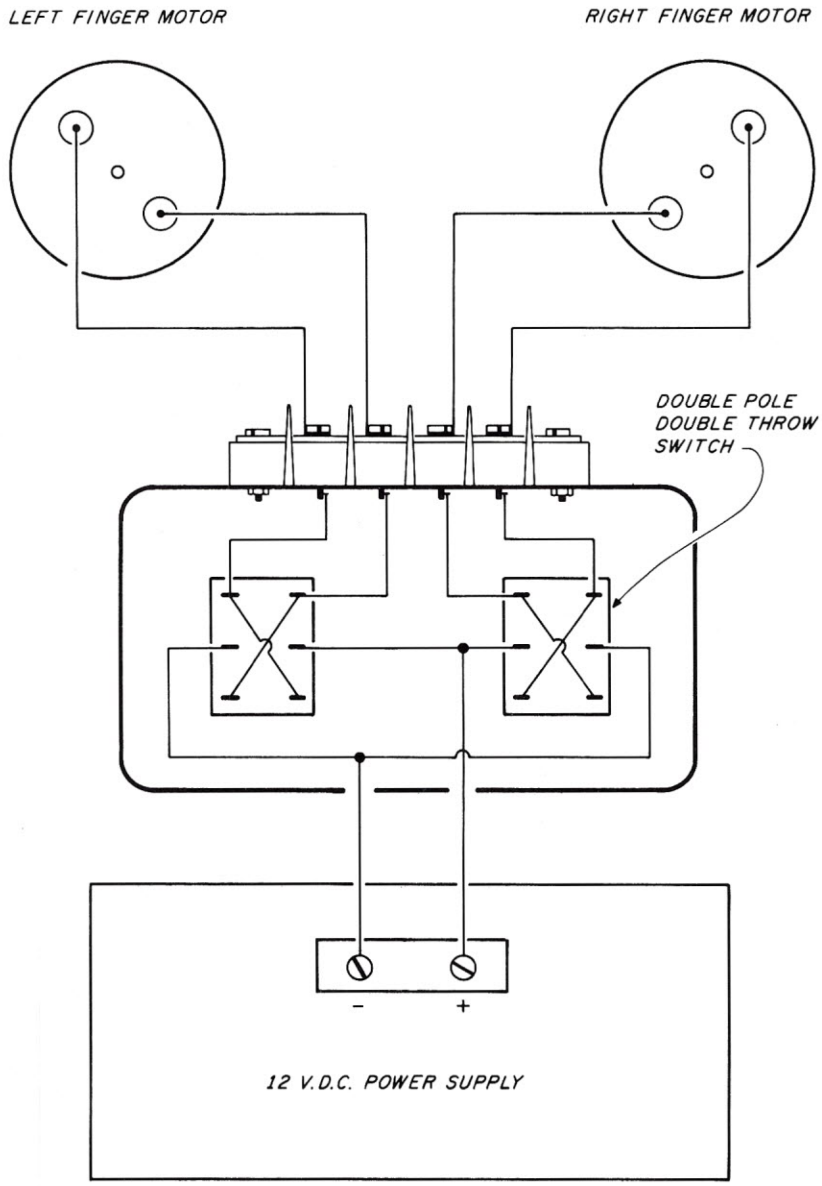
Wire the control box to the power supply and then to the gripper. You are now ready to test the 2-Roll Gripper. Experiment with different springs, conveyor belt lengths, tensions, and surface textures for optimal performance. Other possibilities for transmitting power from the motors to the conveyor belts include using spur gears or small chain drives. Try substituting multiple roller chains with attachments and drive them with sprockets to replace the rubber conveyor belts and pulleys. Experiment with different types of motors and control systems. You may eventually want to servo-control the gripper and integrate it with a robot.

Future Trends. The direction in gripper design is towards a more general purpose or universal gripper that can handle a variety of differently-shaped objects and tools for a diverse range of tasks.

Such grippers must be rugged, compact, and, above all, dexterous. Air cylinders mounted in the base of the gripper probably will continue to be the choice for finger actuation. Electric servo-control motors may become more common with the greater demand for robots of higher dexterity. Using servocontrolled motors to actuate the fingers' motion seems ideal for precision control and increasing the robot's flexibility.

Mechanically driving the gripper's motion remotely around or through a three-degree-of-freedom wrist will probably remain impractical. Three-degree-of-freedom wrists are com-

Figure 3: Control box diagram.



plicated enough without having cables, rotating shafts, or push/pull rods fed through them. Less bulky, flexible power lines and air lines may be fed through a three-degree-of-freedom wrist.

Simple fingers are preferable to avoid complicated multi-jointed fingers and cable systems. It is not necessary to copy the human hand in order to create a gripper that has most of its functions.

To realize the full capability of the 2-Roll Gripper, you should attach it to a three-degree-of-freedom wrist. This allows the gripper to approach an object from the greatest number of angles and directions, thus increasing the number of axes it may be rotated.

Further advancements in robot computer vision systems are essential for more sophisticated grippers like the 2-Roll Gripper to reach their full potential. □

Parts List for the 2-Roll Gripper:

- Two front finger plates made from $^1/_{16}$ inch sheet aluminum (see figure 1).
- Two back finger plates made from $^1/_{16}$ inch sheet aluminum (see figure 2).
- One finger track made from $^1/_{16}$ inch sheet aluminum, 2 inches by 9 inches.
- Two motor pulleys, 0.625 inch by 0.5 inch. A 0.125 inch diameter hole is drilled through as shown in photo 15. Note: All pulleys are machined to leave two small flanges on each end to hold the belts.
- Two drive pulleys 0.625 inch by 0.5 inch. A 0.1875 inch hole is drilled through as shown in photo 15.
- Two conveyor belt drive pulleys, 2.875 inches by 0.5 inch. A 0.75 inch by 0.1875 inch stem is machined down on one end of each of the pulleys for attaching the drive pulleys.
- Four conveyor belt idler pulleys, 1.875 inches by 0.5 inch. A 0.25 inch hole is drilled through as shown in photo 15.
- Six tube spacers, 0.25 inch by 2 inches.
- Eight 2.5 inches by 0.125 inch machine screws and nuts and washers.

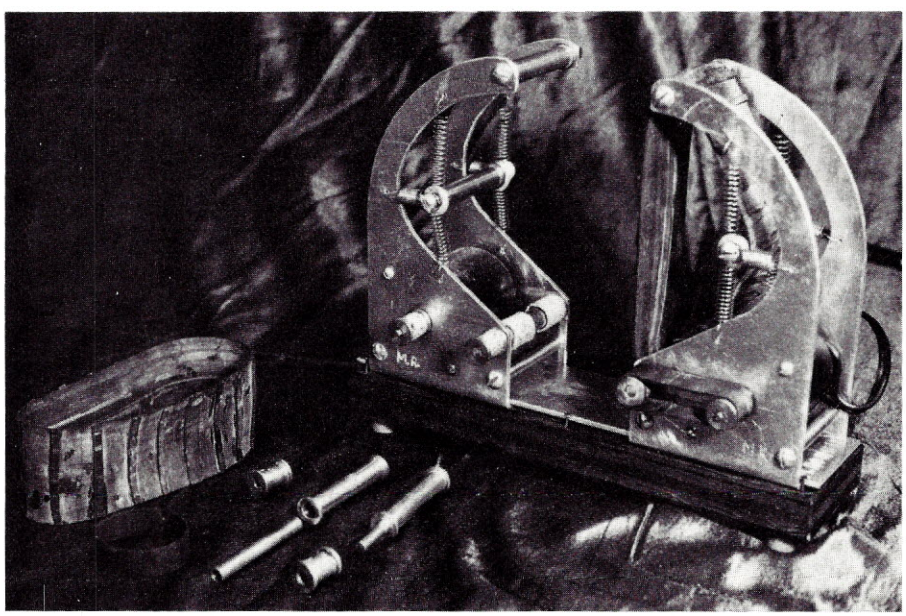


Photo 15: A view of the 2-Roll Gripper with a conveyor belt removed. A duplicate set of pulleys and a motor belt are shown in the foreground.

- Four machine screws and nuts and washers, 0.5 inch by 0.0625 inch.
- Two drive belts, 0.5 inch by 4 inches from bicycle inner tubes.
- Two conveyor belt pulleys, 11 inches by 1.75 inches.
- Twelve springs, 0.25 inch by 0.25 inch. These are available from a well-stocked hardware store. Edmund Scientific offers a 120-piece assortment.
- Two high-torque, 7-rpm, low-speed electric motors. These may be obtained from Edmund Scientific.
- 8-foot lamp cord wire.
- One 12-volt power supply, Radio Shack catalog number 22-124.
- One control box housing, Radio Shack catalog number 270-231.
- Two DPDT center-off switches, Radio Shack catalog number 275-1545.
- One barrier strip with four terminals, Radio Shack catalog number 274-658.

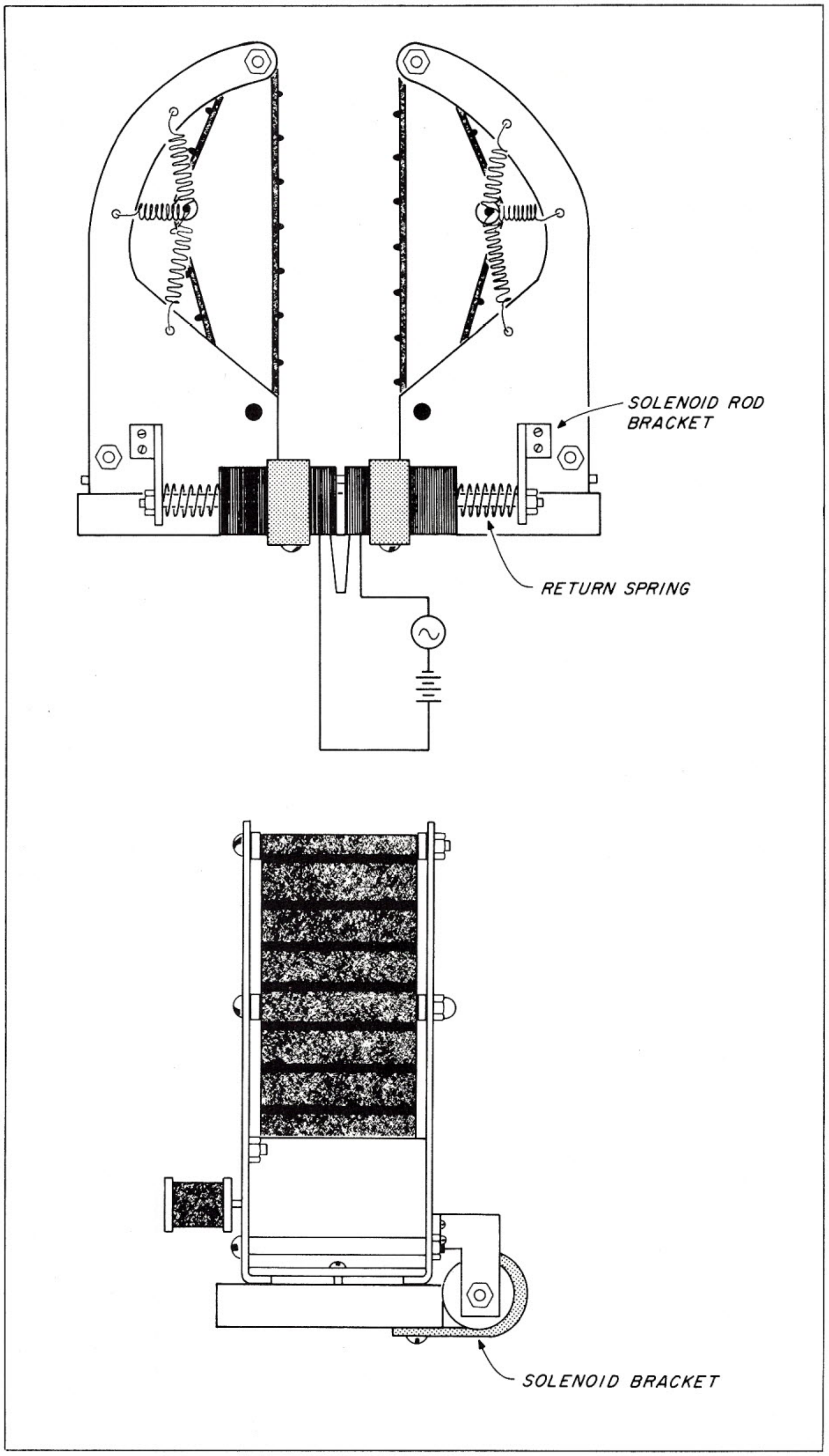


Figure 4: The 2-Roll Gripper's fingers can be actuated by two solenoids.

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Plans for making a simple gripper and motor and control ideas are presented.

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This article covers an interesting new gripper designed to give compliance. Another gripper utilizing an optical detection system for handling fragile objects is discussed.

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We've nearly sold out one back issue, July/August 1982—and supplies of other back issues are getting smaller day by day. On a separate page, we list all back issues currently in stock. Don't miss a single issue...

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One way to guarantee that you'll get all of the *Robotics Age* issues is the eager beaver method. We always mail out newsstand and subscription copies about the same time in each bi-monthly publication period. Knowing this, *Robotics Age* eager-beavers have been reported to camp out at their friendly newsstand awaiting the monthly shipment of their favorite magazine. But this technique of pouncing on your local dealer requires lots of time, exquisite timing, and devotion. We'd even call it above and beyond the call of duty. And—even worse—not every potential dealer carries *Robotics Age* so you might have a hard time if you're in the wrong city.

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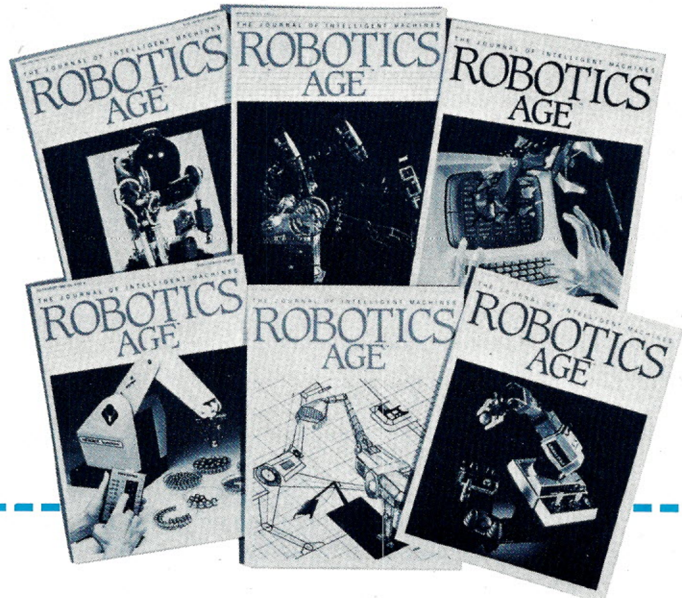
* *All prices and savings are quoted for domestic U.S. subscribers; scaled equivalent savings apply to foreign subscribers. In some countries we have dealer arrangements for subscription and single copy sales.*



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Calendar

FEBRUARY

February 22-24, 1983. San Jose Industrial Productivity Conference and Exposition. San Jose Convention and Cultural Center, San Jose, California. Contact: Public Relations Department, SME, One SME Drive, PO Box 930, Dearborn, Michigan 48128. Phone: (313) 271-1500.

Sponsored by the Society of Manufacturing Engineers, this convention will feature machine tools and equipment for plant maintenance, materials handling, energy conservation, ecology control, and other equipment categories. Some 5,000 manufacturing engineers, executives, and industrial plant personnel are expected to attend. The concurrent conference program will discuss industrial robots, CAD/CAM, and lasers.

APRIL

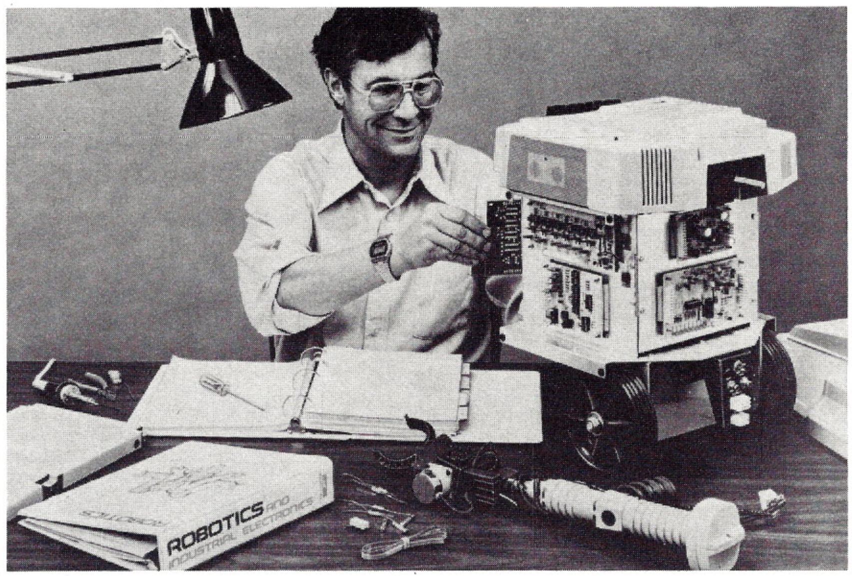
April 13-21, 1983. 13th International Symposium on Industrial Robots/ Robots 7. McCormick Place and Conrad Hilton Hotel, Chicago, Illinois. Contact: Public Relations Department, SME, One SME Drive, PO Box 930, Dearborn, Michigan 48128. Phone: (313) 271-1500.

The theme of Robots 7 is "Robotics: The Emerging Challenge." The technical program is composed of 18 conference sessions, three basic sessions, and four special forums. Topics include robot design, materials handling, design and construction of mobile robot systems, robot safety, vision research, and aerospace applications. The 1983 Joseph F. Engleberger Awards will be presented during the conference. Robots 7 is sponsored by Robots International of the Society of Manufacturing Engineers and the Robot Institute of America.

MAY

May 2-5, 1983. Test & Measurement World Expo. San Jose Convention Center, San Jose, California. Contact: Meg Bowen, Test & Measurement World Expo, 215 Brighton Avenue, Boston, Massachusetts 02134. Phone: (617) 254-1445.

New Products



The Age of Heroes Has Arrived...

On December 1, 1982, Heath held a media event in New York City to announce a new product. The product is the Hero-1 robot shown here in one of the photographs supplied as part of the press kit. Readers who were watching the Today show that morning saw an "interview" with a Hero-1 on television. What we saw at the press conference was a very real, affordable autonomous robot system with on-board computer which is a milestone in the growth of the idea of personal robotics.

We'll have much more coverage of this and other new robots in coming issues. As a last minute addition to this issue as we go to press, here is a quick summary of the characteristics of the Hero-1 by Heath. Hero-1 is a mobile, autonomous robot with a three-wheel rolling carriage base. The on-board computer is a 6808 processor with 4K of scratch memory and an 8-K byte, read-only-memory operating system. The mechanical layout of the device is that of a canister base with a rotating turret for sensors and effectors.

There is a sonar ranging device and a sonic motion detection device as primary object sensors. A photocell can be used to measure light levels. A dynamic microphone, hooked to an 8-bit, analog-to-digital converter, provides the potential for monitoring sound levels and implementing rudimentary voice recognition algorithms. The voice of Hero-1 is provided by a Votrax integrated circuit coupled with software in the machine. Rotation of the turret under program control, through a nearly 360 degree arc, allows profiles to be made of directional sense inputs (sonar ranging, motion detection, light levels).

At the rear of the turret is a gripper and arm with several degrees of freedom. One of the degrees of freedom is rotation of the turret. At the top of the turret is a prototyping board which brings out the signals of the computer's internal bus. This board is intended for use in custom engineering of experimental sensors, and in conjunction with the hands-on course in robotics and microelectronics technology that Heath supplies with this project. This course is one of the most important parts of the product.

Hero-1 is manufactured by the Heath Company, Benton Harbor, MI 49022. It is priced at $1,500 in kit form, $2495 fully assembled at the factory.
CIRCLE 29

New Brochure Describes Rotary Fiber Optic Data Links

Poly-Scientific division of Litton Systems, Inc. has published a new brochure describing their recently developed rotary fiber optic data links.

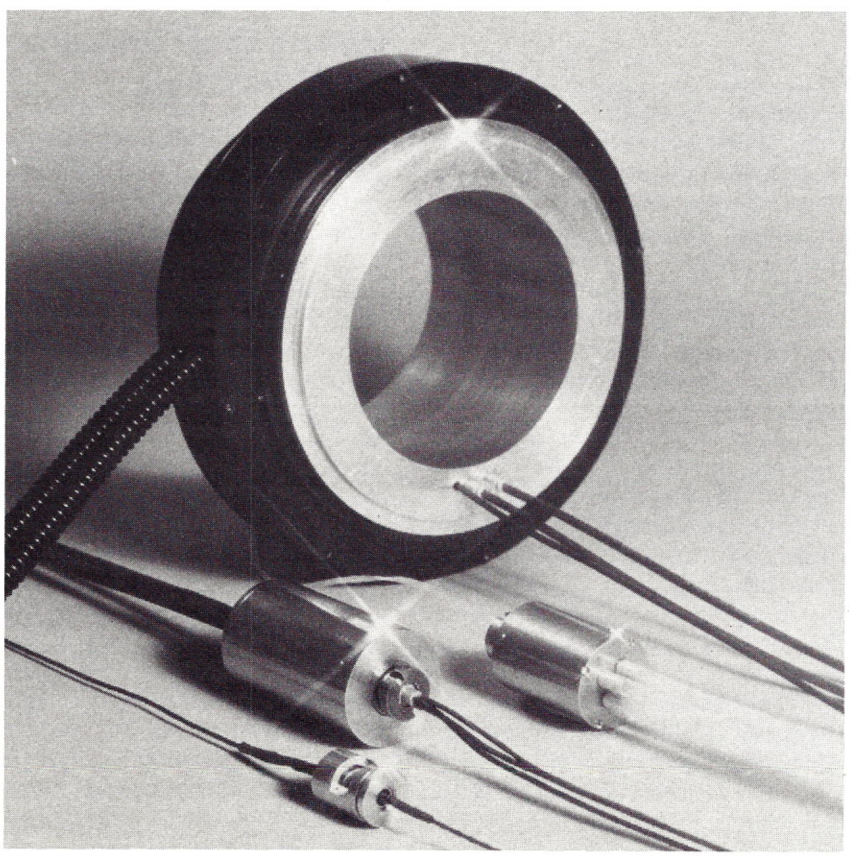
Signal conditioning, multiplexing and driver electronics are combined with a fiber optic rotary joint to provide a fully integrated electro-optic system which can accept either electrical or optical signals while permitting 360-degree system rotation.

The brochure presents dimensional drawings and system parameters for four basic rotary fiber optic data links which can be customized to meet individual system requirements.

Poly-Scientific, the world's largest designer and manufacturer of precision slip rings, is currently producing several configurations of the fiber optic rotary joints.

The simplest version, P/N 3056, accepts an optical signal and transmits it across a rotating interface. This design has one optical channel for signal transmission. For power transmission, the unit can be combined with conventional slip rings or newly developed fiber brush slip rings. Both time division multiplexing (TDM) and double side band amplitude modulation (DSB-AM) electronics are available to increase the data transmission capability of the unit.

For applications requiring more than one fiber optic channel, Poly-Scientific has several options which can accept either optical or electrical signals. Multiple optical circuits can be stacked side by side on the same unit so that the number of possible channels is limited only by the desired length of the package. With this placement of the fiber optics, a clear-through bore can be provided for applications requiring access to the mechanical centerline of the rotary interface.



Multi-optic channel units have also been designed as part of the fiber optic rotary systems, complete with the electronics necessary to convert an incoming electrical signal to an optical signal for transmission across the rotating interface, then change the signal back to an electrical form. The fiber optic rotary joint system can be configured as a repeater to interface with an existing fiber optic signal. In this form, the fiber optic rotary joint accomplishes both rotary optical transmission and amplification of the optical signal. If problems exist with EMI or RFI, the electronics packages can be located remotely in a shielded environment, and fiber optic cable, can attach the joint to the transmitter and receiver circuits. Along with multiplexing capability, the multi-optic channel units can be designed with redundancy switching. Send inquiries to: Vicki Vickers, Marketing Analyst, Poly-Scientific, 1213 North Main Street, Blacksburg, Virginia 24060. Phone: (703) 552-3011. CIRCLE 30

Voice Synthesis Module User's Guide

The Microelectronics Group of General Instrument Corporation has released a user's guide which describes the features and operation of the VSM2128-AL2 Voice Synthesis Module.

The user's guide discusses allophone theory and contains instructions on how the module may be used to construct any English phrase, using its stored allophone set.

For more information, contact: Microelectronics Division, General Instrument Corporation, 600 West John Street, Hicksville, New York 11802. Phone: (516) 733-3107. CIRCLE 31

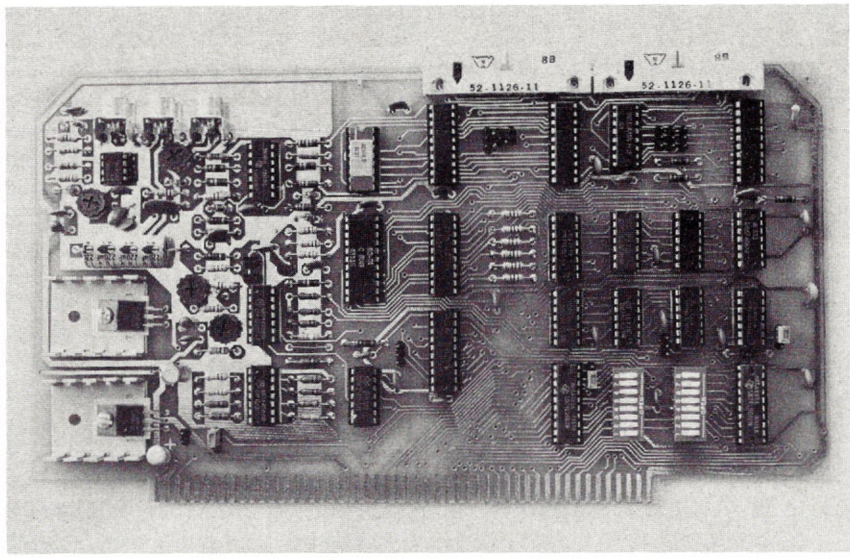
New Products

S-100 Synthetalker

Ackerman Digital Systems' S-100 Synthetalker provides speech synthesis and sound effects from a single board. Using the powerful Votrax SC-01 chip for speech synthesis, the Synthetalker has on-board DAC and mixer to add tremelo, multiple voices, and many special effects. An on-board audio amplifier provides 250 mW into an 8-ohm load.

Another of the variety of possible effects is the provision for external input. Inputs and outputs are connected via handy on-board RCA-type phono jacks for easy mating to audio systems with shielded cables.

The Synthetalker comes with complete manual, including software examples. Unusually clear speech is made possible by software control of pitch on the SC-01 via the 8-bit DAC.



Pricing (in single quantities): kits, $279.95, assembled and tested, $310.00. For more information, contact: Ackerman Digital Systems, Inc., 110 North York Road, Suite 208, Elmhurst, Illinois 60126. Phone: (312) 530-8992.

CIRCLE 32

FORTH For M68000

Hemenway Corporation has introduced the Hemenway/FORTH language system. Hemenway/FORTH™, a superset of the FORTH-79 standard (of the Forth Interest Group), runs under the MSP/68000™ operating system. It is specifically designed to take advantage of the powerful instruction set and 16.7-megabyte address space of the M68000 16-bit microprocessor.

The extended (32-bit) arithmetic capabilities provide higher precision and throughput than can be obtained with FORTH-79. Additional features of the language system include fast address interpreter routines that increase application system performance; a virtual memory with four 1024-byte block buffers that reduces the number of disk I/O operations needed to perform mass-storage operations; and a 128-character maximum size for variable-length word names, which allows exceptional naming flexibility without sacrificing speed within the text interpreter. Yet, despite this high level of capability, the language system requires only 8K bytes of execution memory and runs most FORTH-79 programs unchanged.

A program written in Hemenway/FORTH can execute concurrently with other programs in a real-time environment. This arrangement allows software engineers to make the maximum use of the substantial processing power of the M68000. Further, they can take advantage of operating-system resources to develop powerful extensions to the language.

Hemenway/FORTH can be incorporated now into OEM hardware that runs the MSP/68000 operating system. OEM royalty prices begin at $115 (1-49 units), with quantity discounts and alternative licensing arrangements available. Support documentation includes a two-part manual with User's Guide and Language Reference.

For more information, contact: Walt Patstone, Director of Marketing, Hemenway Corporation, 101 Tremont Street, Boston, MA 02108. Phone (617) 426-1931.

CIRCLE 33

Optical Shaft Encoder Selection Guide

Datametrics • Dresser Industries, Inc. offers an eight-page brochure containing product descriptions and technical specifications of their complete line of optical shaft encoders and programmable limit switches. The selection guide details instrument-grade incremental encoders for light-duty and moderate resolution requirements, heavy-duty incremental encoders for exact position data in rugged environments, plus modular incremental encoders for fast, easy installation on DC servo and stepper motors. Absolute encoders are also offered for demanding industrial applications where non-ambiguous, absolute position feedback is required. Two programmable limit switch configurations for producing sequential control actions as a function of machine timing are also described. For a free copy write Datametrics • Dresser Industries, Inc., 340 Fordham Road, Wilmington, MA 01887, (617) 658-5410.

CIRCLE 34

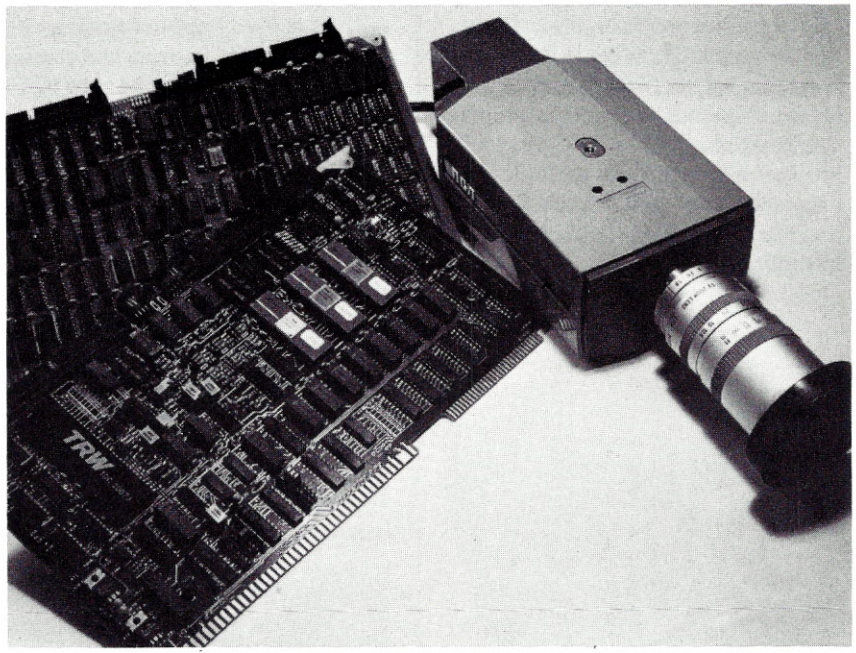
New Products

IP-512 Real-Time Image Processor and Graphic Controller

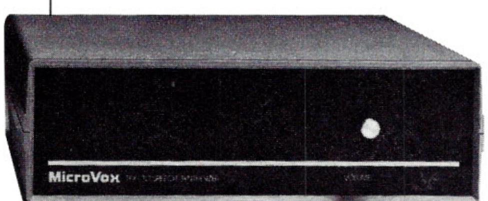
The IP-512 family of board-level image processors and color graphic controllers are plug-compatible with both the Intel Multi-Bus and DEC Q-Bus.

The IP-512 digitizes and stores a camera analog video input signal at 30 or 60 images per second and produces video output signals from digitized image data for black and white or RGB color displays. The IP-512 can store a 512 by 512 by 8 bits/pixel frame image. SYNC circuitry is provided to manipulate display pixel pan and scroll.

Applications of IP-512 include robotic vision, general image processing, teleconferencing, thermal infrared imagery, and computer graphics. For more information contact: Robert Wang, App. Eng., Imaging Technology Inc., 61 North Broadway, Salem, New Hampshire 03079. Phone: (603) 893-6415.
CIRCLE 35



Second Generation Text-to-Speech



Micromint, Inc. has announced MICROVOX, a second-generation text-to-speech synthesizer. The MICROVOX provides a high level of speech intelligibility and voice quality.

At only $295.00, MICROVOX offers: phoneme-based speech synthesizer chip, 64 crystal-controlled inflection levels, text-to-phoneme algorithm, 750 character buffer (optionally expandable to 1.7K characters), full ASCII character set recognition, adjustable data transmission rate (75-9600). RS-232-C or parallel connector, X-on/X-off handshaking, phoneme access modes, music and sound effects capability (programming language for notes included), on-board amplifier and power supply, spelling output option.

MICROVOX is available from: The Micromint, Inc., 917 Midway, Woodmere, New York 11598. Phone: (516) 374-6793. CIRCLE 36

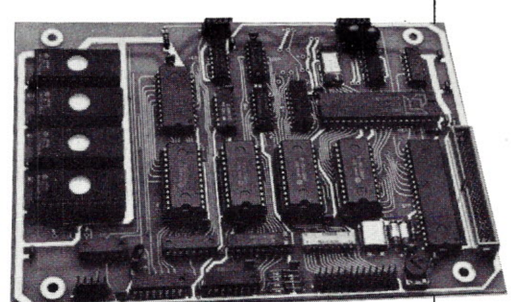
Hart-09 Single-Board Computer

Hart Scientific has introduced a single-board computer which uses the Motorola 6809 microprocessor. Its small size and powerful potential make this stand-alone microcomputer an ideal choice for dedicated OEM applications in data processing, instrumentation, and industrial automation.

The HART-09 features a standard RS-232-C port, five 16-bit timer/counters, an 8-bit D/A converter, 1K bits of non-volatile RAM, 64K EPROM and RAM memory, hex keypad interface, and a general-purpose parallel port for interfacing with a digital display, printer, floppy disk drive, or other peripheral.

The modular, multitasking operating system supports a wide variety of I/O devices. Extensive language support allows application programs to be written in BASIC, assembly language, COBOL, or Pascal.

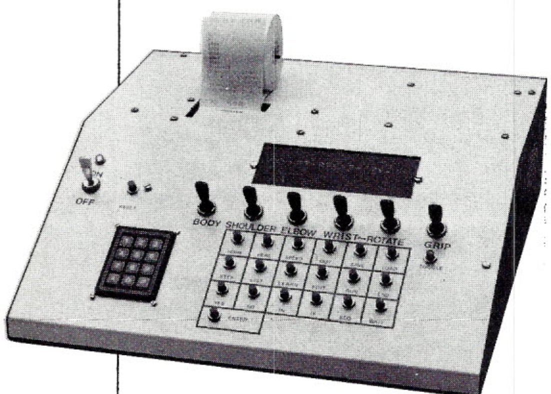
The manufacturer offers full applications support and accessories, such as a power supply, digital display, and hex keypad. Ask for descriptive bulletin MR-2 from: Hart Scientific, P.O. Box 934, Provo, Utah 84630. Phone: (801) 375-7221. CIRCLE 37



New Products

RobotEx Controller

The RC-101 robot controller simplifies robot programming and operation by combining manual "teach-in" programming, decision making capability, and numerous interfaces in one unit. The combination of an RC-101 and a low-cost micro-robot is useful to both companies interested in evaluating the potential of robots, and educational institutions.



The RC-101 supports a wide range of applications from pick-and-place routines to more complex applications requiring interactive decision making. The controller can be programmed in extended RBASIC through an optional keyboard. Standard interfaces include six switch inputs and four photocell inputs.

Software is available to control the Mitsubishi RM-101 Movemaster and Sandhu Machine Designs XR-1 Rhino micro-robots. Switching from one robot to another is a simple matter of changing software and cables.

Future interfaces will allow simultaneous control of six motors. A controller which can operate six pneumatic, 4-way valves is also being developed.

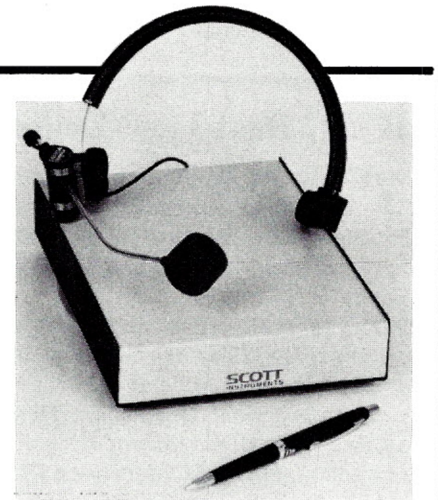
RTROL language software is now available for the Apple II Plus.

The standard RC-101 sells for $2260. For more information contact: RobotEx, 111 E. Alton Ave., Santa Ana, CA 92707. Phone: (714) 556-8679.
CIRCLE 38

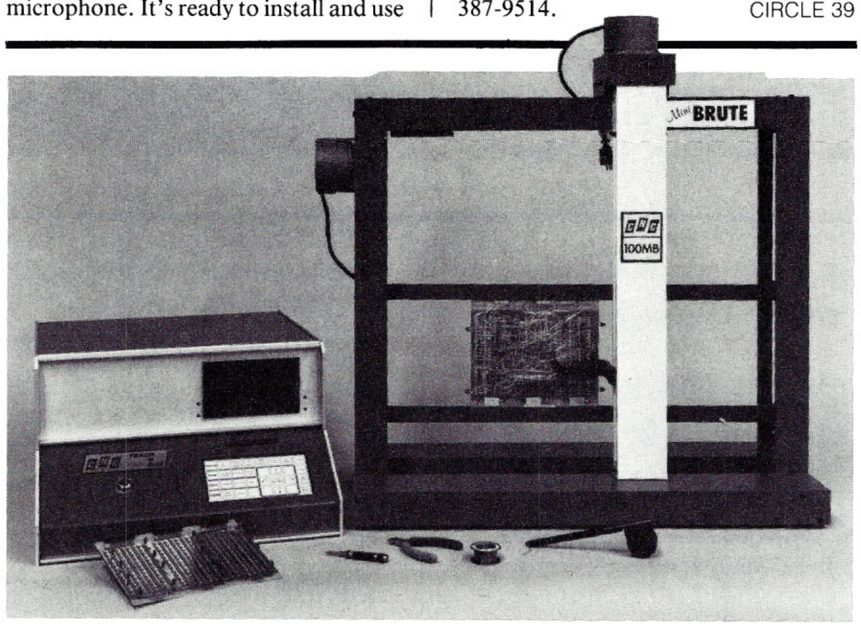
Shadow/VET

Scott Instruments' Voice Entry Terminal gives Apple-compatible computers the ability to listen and respond to human speech. The Shadow/VET terminal contains its own memory and training software. Because it is virtually transparent to the Apple, it is ideal for education and experimentation with voice-controlled robots.

The Shadow/VET terminal can be programmed easily in BASIC or assembler using built-in interface routines, or it can be trained off-line for use with existing software. It comes with complete user manual, interface card with 16K RAM, preprocessor, system software, and noise-canceling headset microphone. It's ready to install and use immediately.



For information, contact: Scott Instruments, 1111 Willow Springs Drive, Denton, Texas 76201. Phone: (817) 387-9514. CIRCLE 39



Teach 'N Run

Computer Numerical Control Corporation has unveiled an intelligent programmable microprocessor controller, the TEACH 'N RUN. The heart of the TEACH 'N RUN is a Z80 processor with 16K RAM and 2K PROM that can be programmed via the keyboard and can store over 9,000 points on a 5-¼ inch single-sided, single-density floppy disk. The TEACH 'N RUN has a positioning rate up to 500 inches/minute, 0.005 or 0.1 inch/step resolution and can drive 2-axis, 4-phase stepping motors.

The TEACH 'N RUN is a unique and highly useful tool which drastically reduces cost in automated position control or robotics applications. Delivery time is eight to ten weeks. The price is $3,500, complete with motor drivers and floppy disk.

For more information, contact: Computer Numerical Control Corporation, 150N New Boston Street, Woburn, Massachusetts 01801. CIRCLE 40

Classified Advertising

Robotics Classified Advertisement Order Form

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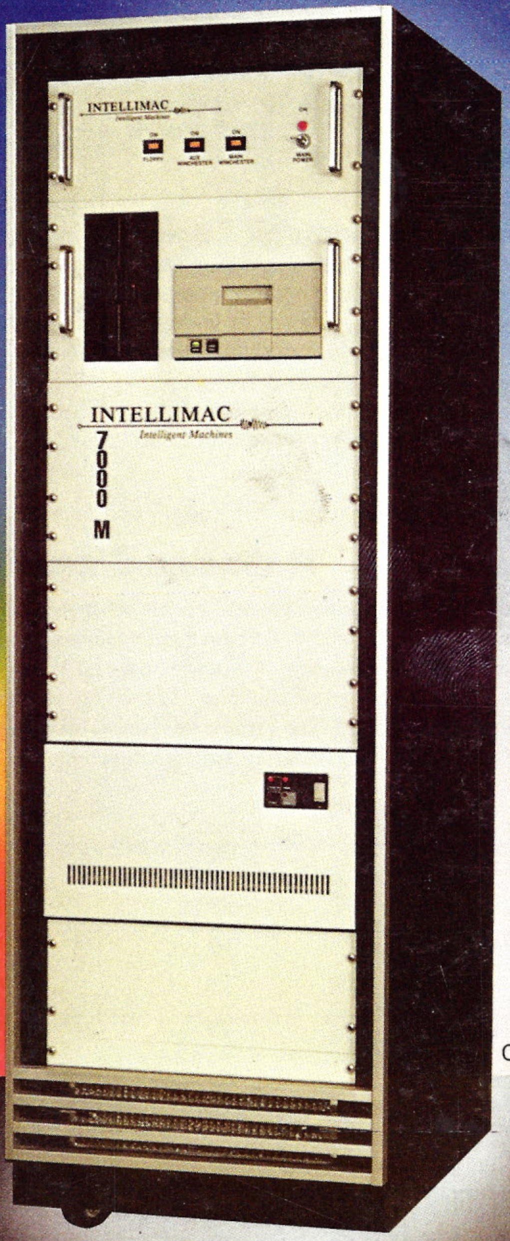
INTELLIMAC

7000 M

New 32-Bit Multi-User Computer System with VAX*-like Speed + UNIX** + Ada***

The IN/7000M from INTELLIMAC is a state-of-the-art general purpose computer system. Based on the powerful MC68000 microprocessor, the 7000M supports multiple users and multi-tasking under UNIX Version 7 and/or the INTELLIMAC IN/MSX Multi-System Executive with TeleSoft Ada.



Standard Hardware Features:

- 8MHz single-board 68000 computer
- 21-slot Multibus**** chassis
- Multi-processor capable
- 256 KByte RAM (on CPU card)
- 1 MByte ECC RAM on Multibus (up to 8 MByte)
- Memory Management Unit (MMU)
- 8-line RS232C serial I/O
- 160 MByte Winchester Disk
- 8 MByte fixed plus 8 MByte removable cartridge disk
- 1.6 MByte 8" floppy
- 72" steel cabinet, rugged casters

Software Available:

- *Unix Version 7* ("C", FORTRAN 77, COBOL, Pascal, BASIC-Plus, Utilities)
- *IN/MSX Multi-User Ada* (TeleSoft-Ada and Pascal, 68000 Assembler, NASA Path Pascal, Ada Utilities, Applications)

CIRCLE 9

Designed for high reliability, maintainability and availability (RMA), the 7000M's subsystems have very high MTBF's—many exceeding 15,000 hours. Program benchmarks indicate that the 7000M can perform at 50% to 150% of the speed of the DEC VAX 11/780, depending on operating system, language, and number of users.

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